SACCADIC EYE MOVEMENT MEASUREMENTS IN THE NORMAL EYE

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SACCADIC EYE MOVEMENT MEASUREMENTS IN THE NORMAL EYE

Investigating the clinical value of a non-invasive eye movement monitoring apparatus.

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ABSTRACT

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Keywords: saccadic eye movements (SEM), infrared eye tracker, saccadic parameters (SP), repeatability, aging, oblique directions, working distance, dioptric blur, cataract simulation.

Clinicians are becoming increasingly aware of the effect of various pathologies on the characteristics of saccadic eye movements. As such, an efficient and non-invasive mean of measuring eye-movements in a clinical environment is of interest to many. The aim of this thesis is to investigate the clinical application of a non-invasive eye movement recording technique as a part of a clinical examination.

Eye movements were measured using an IRIS 6500 infrared limbal eye tracker, which we customized for the direct recording of oblique eye movements as well as horizontal and vertical. Firstly, the eye-tracker itself was assessed. Visually normal observers made saccadic eye movements to a 10° stimulus in eight directions of gaze. Primary (ANOVA) and secondary analyses (mean error less than 5%) resulted in acceptance that averaging four measurements would give a representative measurement of saccadic latency, peak velocity, amplitude and duration. Test-retest results indicated that this technique gives statistically ($\pm$ 1.96*$STDEV_{Difference}$) repeatable responses.

Several factors that could potentially influence clinically based measures of eye-movements were examined. These included, the effect of ageing, viewing distances, dioptric blur and cataract. The results showed that saccadic latency and duration are significantly ($p< 0.05$) longer in older (60-89 years) observers compared to younger (20-39 years). Peak velocity and amplitude were not significantly affected by the age of the observer. All saccadic parameters (SP) were significantly affected by direction (Chapter 5). The compact nature of this eye movement methodology is obtainable since there is no significant effect on viewing distance (300 cm vs. 49 cm) (Chapter 6). There is also no significant effect of dioptric blur (up to +1.00DS) on any of the four SP. In contrast, a higher level of defocus (+3.00DS) has a larger probability of interfering with the measurements of peak velocity and duration (Chapter 7). Saccadic eye-movements were also recorded whilst normally sighted subjects wore cataract simulation goggles. The results suggested that the presence of dense cataract introduces significant increases in saccadic latencies and durations. No effect was found on the peak velocities and amplitudes. The effect of amblyopia on SP was also investigated in order to examine if this methodology is able to detect normal from abnormal responses (i.e. increased saccadic latencies). This set of data (Chapter 9) showed that using IRIS 6500, longer than normal latencies may be recorded from the amblyopic eye but no consistent effect was found for the other SP (peak velocity, amplitude, duration).

Overall, the results of this thesis demonstrate that the IRIS 6500 eye-tracker has many desirable elements (it is non-invasive; comfortable for the observers and gives repeatable and precise results in an acceptable time) that would potentially make it a useful clinical tool as a part of a routine examination.

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CHAPTER 1:

Introduction

Many clinical investigators have used quantitative recordings and analysis of eye movements in order to investigate a variety of neurological, ophthalmological as well as psychiatric disorders (Sweeney, *et al.* 2002). This increased use of eye movements in general and saccades more specifically, might be due to the fact that much information concerning the cerebellar function and the brainstem is obtained through their dynamics (Serra, *et al.* 2003). It is also reported that eye movements show a significant consistent pattern thus it provides a non-invasive approach to understand deeper and better several abnormalities in adults as well as in children (Langaas, *et al.*1998). Furthermore, a systematic representation (i.e. measurements of error as well as reference values) of more than one saccadic property (latency, peak velocity, amplitude and duration) across a wide age range and different directions of gaze (horizontal, vertical and oblique) is required since this matter is under represented in the whole field of objective eye movement recording.

Feldon and Unsold (1982), using an infrared oculography technique, reported that eye movements recording might provide an accurate and sensitive method for classifying and following up patients with Graves' disease. In addition, Koca, *et al.* (1992) suggested that saccadic eye movements could provide an additional parameter for evaluating the progress in patients with myotonic dystrophy. Two other studies reported the significance of saccadic eye movement recordings in the evaluation of therapy and diseases progression in patients with multiple sclerosis (Van Dongen, *et al.* 1991; Serra, *et al.* (2003). In more detail, Van Dongen, *et al.* (1991) reported that saccadic latencies were significantly improved (in 63% of the cases) providing a successful mean in detecting treatment effect in patients with multiple sclerosis. In summary, there is a large body of studies that have used eye movement measurements to diagnose and provide objective quantitative documentation of several dysfunctions. This may give evidence for the reliability and practicability of measuring eye movements as part of a routine examination.

In a clinical environment, the recording eye movement apparatus should be able to detect any kind of abnormal eye movements and have repeatable measurements. The selected method must also be non-invasive and comfortable for the patient as well as being easy for the observer to perform without requiring any training. Other important factors are being inexpensive and easy to use without the need of an experienced clinician. Therefore, in our study an infrared eye tracker was considered as the most suitable recording apparatus. The IRIS 6500 was selected due to the fact that has being used extensively on nystagmus research (Abadi, *et al.* 1997; Abadi and Scallan, 1999; Abadi and Scallan, 2001). This eye tracker has been also used in a study were they investigated the sensitivity of eye movements and visual evoked potentials in the evaluation of therapy of patients with multiple sclerosis (Van Dongen, *et al.* 1991). Recently, Constantinidis, *et al.* (2003) also used the IRIS 6500 to investigate the effect of direction on saccadic performance. This literature review provides evidence that this infrared eye-tracker is commonly used in research.

The aim of this thesis is to investigate the clinical value of a non-invasive eye movement recording technique. This subject was examined from several aspects. Firstly, a good clinical test should be repeatable with good precision from a quickly achieved measurement. Therefore, Chapter four investigates those features by establishing the minimum number of measurements required in one session that would give a representative value of saccadic metrics (latency, peak velocity, amplitude and duration) in a certain time without compromising precision. It also investigates the test – retest repeatability in two different occasions. Chapter five investigates the effect of a very important physiological variable – ageing – and the effect of direction in the different saccadic parameters. In this chapter normative data of several saccadic parameters (latency, duration, peak velocity and amplitude) were established for eight directions of gaze [temporal (TEM), nasal (NAS), up (UP), down (DOWN), up nasal (UN), down temporal (DT), up temporal (UT) and down nasal (DN)] in different age groups. This will allow comparison between normal responses across a wide age range with those from patients. In a clinical environment, the compact nature of a clinical tool is an advantage. Thus, Chapter six investigates if a reduction of the viewing distance (from 300 cm to 49 cm) would introduce any effect on the metrics of saccadic eye movements. In addition, Chapters seven and eight investigate several other factors that may be encountered clinically such as defocus and age-related disease (cataract). This approach was followed in order to verify that changes in the saccadic dynamics are due to motor factors rather than reduced visibility of the target.

A review of the literature revealed that amblyopic observers introduce changes in some saccadic parameters. Therefore, we decided to examine the effect of different levels and types of amblyopia on saccadic eye movements. Finally, Chapter nine investigates if this non-invasive eye movement methodology is able to distinguish between normal and abnormal (amblyopic) responses.

CHAPTER 2:

Background

2.1 Eye movements

Eye movements play an important role in everyday life since humans cannot completely interpret a complex visual scene with a single fixation. Leigh and Zee (1999) suggested that a human sees clearer when images are positioned on the retina and more specifically on the fovea, the most sensitive part of the eye with the greatest visual acuity. Hence human eyes voluntarily and/or involuntarily fixate on elements of a scene or objects, which will provide the most relevant information depending on the purpose of the observer. The more information available, the longer ones eyes will stay on that object (Yarbus 1967).

There are several different types of eye movements that create the essential conditions for perception during fixation in variety of situations. Those types are:

1. Vergence
2. Vestibular and optokinetic
3. Smooth pursuit
4. Saccades

2.1.1 Vergence

Vergence movements are slow eye movements that obtain and maintain binocular single vision. Vergences are also known as disjugate movements due to the fact that the two eyes simultaneously move in opposite directions. They are mainly horizontal (convergence[1], divergence[2]) but vertical vergence and cyclovergence can occur.

Pure vergence movements have a maximum velocity of approximately 20 deg/sec (Ansons and Davis, 2001) and their latencies[3] are approximately 160 msecs (Leigh and Zee, 1999; Student Neurology, 2001).

Several studies reported that converging movements (20^{Δ}) have greater amplitudes than diverging (6^{Δ}-8^{Δ}) ones and vertical vergence (3^{Δ}-4^{Δ}) is smaller than horizontal vergence (Von Noorden, 1995; Leigh and Zee, 1999; Student Neurology, 2001).

The vergence system is also unique in being able to generate uniocular eye movements. For example, if a target was placed exactly in front of the right eye and slowly brought closer to the observer, the right eye would remain stationary but the left eye would converge (Student Neurology 2001). The development of the vergence system's full and accurate capabilities occurs by 2-3 months of age (Ansons and Davis, 2001).

2.1.2 Vestibular and Optokinetic eye movements

During everyday life people live in a complex environment where head movements produce increased retinal-image motion generating blurry vision. Vestibular and optokinetic are two oculomotor systems, which are considered together due to their common purpose, which is to maintain images steady upon the retina during head movements (Ciuffreda and Tannen, 1995; Leigh and Zee,

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[1] Convergence is the movement when the eyes turn inwards or towards each other.
[2] Divergence is the movement when the eyes turn away from each other.
[3] Latency is the time taken between the appearance of a target and the beginning of the vergence response.

1999; Ansons and Davis, 2001). Furthermore, the vestibular system produces eye movements that compensate transient head movements whereas the optokinetic system is responsible for compensating sustained head movements. In addition, when the response from the vestibular system begins to decline and eventually ceases; the optokinetic system gradually becomes activated and replaces the vestibular system while the rotation continues (Ciuffreda and Tannen, 1995).

The latency of the vestibulo-ocular reflex varies between 7-15 msecs (Leigh and Zee 1999) whereas the latency of the optokinetic nystagmus[4] is approximately 140 msecs (Ciuffreda and Tannen, 1995). The latency of the former is defined as the time course from the head rotation to the initiation of the compensatory eye movement (vestibulo-ocular reflex). In addition, the latency of the optokinetic nystagmus is defined as the time difference between the head movement and the time when the optokinetic system responded. These eye movements also have peak velocities that vary and can be as fast as 300 deg/sec (Student Neurology 2001).

According to Anson and Davis (2001), the development of the horizontal vestibular ocular reflex (VOR) occurs at birth whereas the symmetry of the optokinetic nystagmus develops at about 4-6 months of age.

2.1.3 Smooth pursuit movements

Smooth pursuits are tracking eye movements of discrete objects of interest moving in our surroundings. Its main function is to match eye velocity with target velocity. They are also described as conjugative eye movements because they are

[4] Nystagmus is irregular, repetitive involuntary eye movements of variable direction, amplitude and frequency

responsible for the synchronous movement of the eyes in the same direction (Von Noorden, 1996).

The latency of smooth pursuit eye movement is defined as the time difference between the stimulus onset and the start of the pursuit and is approximately 100 msecs (Cuiffreda and Tannen, 1995; Leigh and Zee, 1999). In addition, peak velocity does not usually exceed 30-40 deg/sec. Most eyes have difficulties in matching their velocity as close as possible with the one of the target during tracking an object, therefore this mismatch often results in either a lag behind the target or a catch up saccade in order to maintain fixation (Ansons and Davis 2001). Smooth pursuit eye movement are also under control of a system capable of continuous modification of the motor output in relation to the visual input. Thus they are influenced by the nature of the stimulus and how it behaves as well as by the subject's attention. There are several situations where the VOR is suppressed by the pursuit system in order to maintain stable eye tracking. In humans, the smooth pursuit system is fully developed at 3-4 months of age.

2.1.4 Saccadic eye movements

Saccades are accurate, high-velocity, eye movements used in all everyday tasks. There are several different types of saccadic eye movements that can be classified as: volitional, reflexive, express, spontaneous, quick phases and refixation saccades.

Volitional saccades are defined as the voluntary eye movements that are made for a specific purpose. They are categorized as: a) predictive b) memory-guided c) antisaccades and to command. Predictive (or anticipatory) saccades are generated when one is searching for the appearance of a target in a certain location. Memory guided saccades are the movements that are generated to a location that a target used to be presented. Antisaccades are generated when one is directed to look in the opposite direction to that of the target. Saccades *to command* are those that are generated due to the appearance of cue (Leigh and Zee, 1999).

Reflexive saccades occur when a stimulus (visual or auditory) appear unexpectedly within the visual field. This type of saccades to visual and auditory targets have been used in neurophysiological studies in order to investigate the hypothesis that the saccadic system uses different pathways in the central nervous system depending the nature of the target (Yao and Peck, 1997).

Express saccades are the ones with very short latency (i.e. 90-130 msecs). They can be obtained when a stimulus is presented after the fixation target has disappeared (gap effect[5]) (Fischer and Ramsperger, 1984; Leigh and Zee, 1999; Leigh and Kennard, 2004).

Other types of saccades are the *spontaneous* and the *quick phases* saccades. Spontaneous saccades are the ones that are elicited randomly without any particular requirement and/or purpose. Quick phases of nystagmus occur either during vestibular and/or optokinetic stimulation or as an involuntary reset of the eyes (Leigh and Zee, 1999).

Finally, the fast eye movements that enable us to redirect our line of sight on the fovea are called *refixation saccades*. This type of saccadic eye movement can be divided into two further categories: a) normometric (or orthometric) and b) dysmetric. Generally, it is reported that the combined action of two components in

[5] Gap effect is the condition when the central fixation point disappears and after a predictable (i.e. 200msecs) or unpredictable gap period the fixation point reappears in an eccentric position.

the neural controller signal of the saccadic system, the pulse and the step elicit saccadic eye movements. The pulse is responsible for moving the eye in the new position and the step is responsible for holding the eye in this new position (Robinson, 1964; Bahill and Troost, 1979; Ciuffreda and Tannen, 1995). Therefore, a normometric (orthometric) saccade consists of a single-step, accurate movement and it occurs because the step and the pulse – controller signal are equal. In contrast, dysmetric saccades are inaccurate saccades that can be single-[hypometric (the movement undershoots) or hypermetric (the movement overshoots)] or multiple-step. In addition, hypometric single-step saccades are defined as the movements when the observer achieves smaller amplitude than the required one. They can be differentiated into glissadic (or sliding) saccades, which gradually approach the target position and slow saccades that are extreme cases of glissadic undershoot with velocities as low as those in vergence eye movements. Multiple-step dysmetric saccades, on the other hand, include corrective saccades, which are closely spaced. The occurrence of a corrective saccade increases when the first movement is inaccurate. In this case, an additional saccadic movement appears with smaller amplitude and latency of 130 msecs in order to bring the fovea in the final position (Henson, 1978). It is reported that corrective saccades appear 150 msecs after the primary saccade ended (Bahill and Stark, 1975).

The nature of the saccadic system is an issue that has given contradictory views. The first notion suggested that saccades have a ballistic nature, which means that since a specific saccade has been "programmed" no external or internal parameters can influence their course of action (Westheimer, 1954). Several studies (Zee, *et al.* 1976; Van Gisbergen, *et al.* 1987; Wouters, *et al.* 1998; Leigh and Zee, 1999) have described saccades as non-ballistic due to the fact that the central nervous system appeared to be able to change saccades at any stage. Zee *et al.* (1976) suggested that slow saccades occurring in some neurological disorders could be interrupted by a change in target position even after the eye has already started to move. In addition, Van Gisbergen *et al.* (1987) reported that saccadic trajectories have been changed during the course of movement when a two-step target is presented due to the fact that normal subjects would make a single curved saccade instead of two successive ones.

Saccadic eye movements enable us to redirect our line of sight in order to bring a new part of the visual field to the fovea (Wouters, *et al.* 1998; Leigh and Zee, 1999). It is reported that although saccadic eye movements can be initiated in neonates, they are not accurate and the ability to change fixation with a single step saccade is not fully developed until the first year of age (Ansons and Davis 2001). Although the main function of voluntary saccades in primates is to bring the images onto the fovea, saccades also produce quick phases of nystagmus during passive head movements. This occurs for two reasons, firstly to inhibit the vestibular and optokinetic nystagmus from driving the eyes to extreme orbital position and secondly to enable the observer to scrutinize the oncoming visual scene in order to obtain as much visual information as possible (Leigh and Zee, 1999).

The saccadic system is also described as a sample-data (or discrete) system providing brief, high-resolution "samples" of the world to the brain enabling the latter to perform more complex task such as identification and perception (Ciuffreda and Tannen, 1995).

2.1.4.1 Saccadic Parameters

Several parameters can be used when defining and measuring saccades. These include latency, peak velocity (PV), duration, amplitude, peak acceleration and skewness. Most studies, however describe saccades on the basis of latency, peak velocity (PV), duration and amplitude (or accuracy) (Figure 2.1.4.1). These last two parameters are interrelated: to establish if a saccade is accurate or not we need to establish first its amplitude and compare it with the expected value.

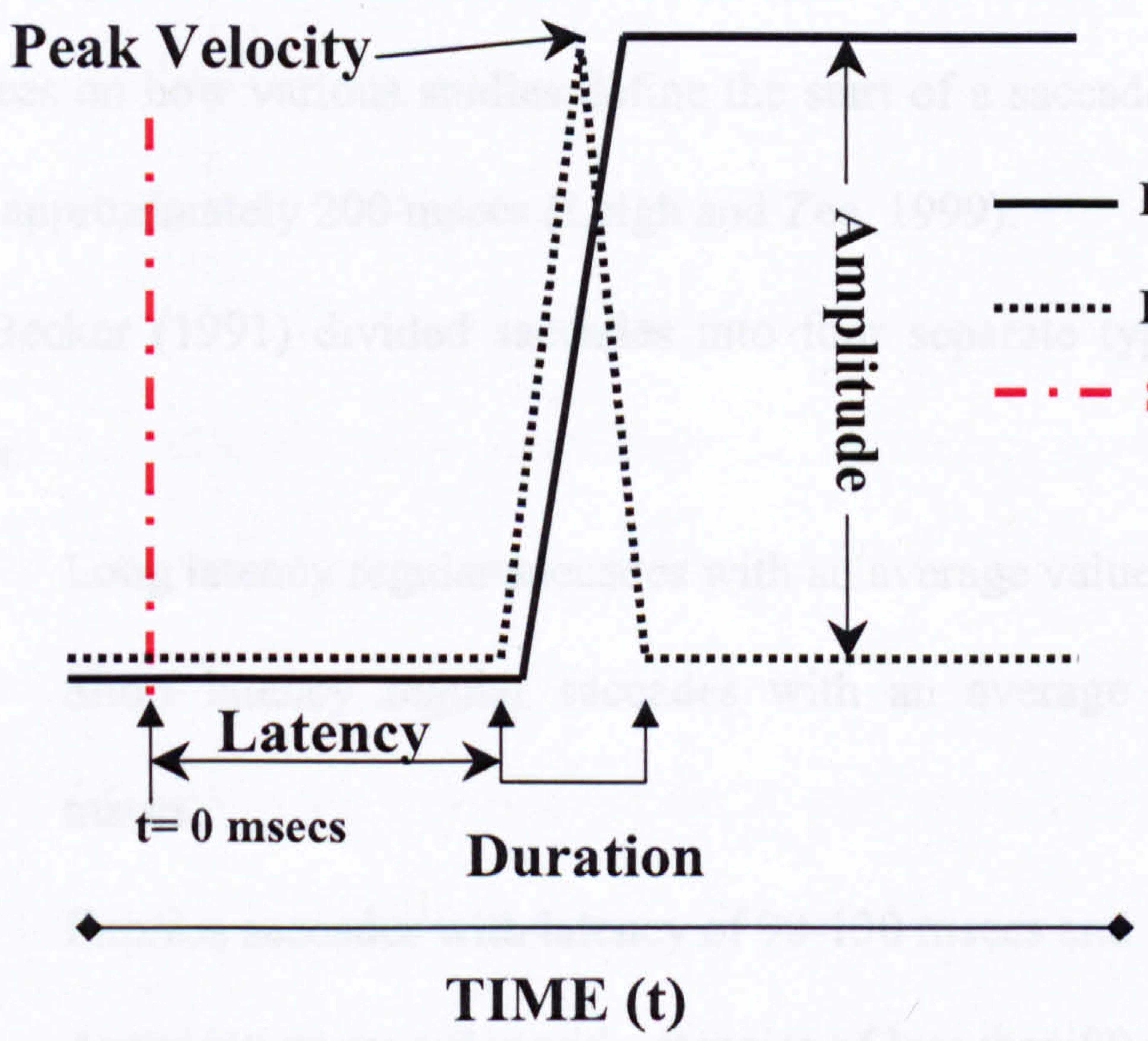

Figure 2.1.4.1: A simple diagram with some saccadic parameters and how they are defined. The black trace represents the eye position, the black dotted trace represents the velocity profile of the eye whereas the red dotted trace represents the stimulus where t=0msecs. The magnitude represented along the x-axis is time (t).

2.1.4.1.1 Latency

Latency is the time interval between the appearance of the target and the start of the saccadic eye movement. This represents the time that the ocular motor system needs to process the signal before it reaches the extraocular muscles (Ansons and Davis 2001). Several studies have used different ways to identify the start of a saccade. Sharpe and Zackon (1987) reported that the start and end of a saccade was delineated by the experimenter (i.e. cursors were placed on the eye position profile by eye). In contrast, Bahill, *et al.* (1981) using a photoelectric methodology, and Abel, *et al* (1983) using an infrared technique, defined the beginning of a saccade at the points where the eye velocity exceeded a threshold of 5 deg/sec. Furthermore, Baloh, *et al* (1975), using electroculography, established a minimum velocity (i.e when the eye exceeded 40 deg/sec) and time (i.e. for longer than 30 msecs) for identifying the start of a saccade. Despite the differences on how various studies define the start of a saccade the normal mean value is approximately 200 msecs (Leigh and Zee, 1999).

Becker (1991) divided saccades into four separate types based on their latencies:

i) Long latency regular saccades with an average value of 230 msecs,

ii) Short latency regular saccades with an average value of 150-200 msecs,

iii) Express saccades with latency of 90-130 msecs and

iv) Anticipatory saccades with latencies of less than 80 msecs

This parameter is highly dependent from a variety of factors such as the nature of the target, its predictability, the patients' motivation and attention and ageing. Generally, it has a diagnostic importance due to the fact that it reflects several aspects of visual processing (Leigh and Zee 1999).

The most important factor that has been investigated in relation to saccadic latency is the effect of ageing. In spite of the differences in the several methodologies used, there is a general agreement that latency (reaction time) is dependent on senescence. Older subjects show prolonged latencies compared to younger ones in horizontal (Spooner, *et al.* 1980; Abel, *et al.* 1983; Warabi, *et al.* 1984; Sharpe and Zackon, 1987; Hotson and Steinke, 1988; Pitt and Rawles, 1988; Tedeschi, *et al.* 1989; Versino, *et al.* 1992; Huaman and Sharpe, 1993; Wilson, *et al.* 1993; Moschner and Baloh, 1994; Baloh, *et al.*1996; Fahle and Wegner, 2000) as well as in vertical directions (Hotson and Steinke, 1988; Huaman and Sharpe, 1993; Fahle and Wegner 2000). Numerous studies have also reported a greater inter-subject variability within the elderly (60-80 years) than the one observed in the younger groups (Spooner, *et al.* 1980; Abel, *et al.* 1983; Moschner and Baloh, 1994; Shatig-Antonacci, *et al.* 1999).

In 1987, Sharpe and Zackon used different types of target (predictable[6], unpredictable amplitude target[7] and unpredictable timed targets[8]), and reported that latency increased with senescence in all these conditions. The same conclusion that prolonged latencies in the elderly is independent to target type, was also reported few years later by Wilson, *et al.* (1993).

There are several discrepancies on the size of the delay reported. Abel, *et al* (1983) reported that older observers showed 45 msecs longer latencies than younger ones, whereas Warabi, *et al.* (1984) reported an average increase of 100 msecs between the two groups. In addition, Moschner, *et al.* (1994) reported the smallest difference, approximately 20 msecs, between the age groups. These differences can be attributed either to the different recording methods, the sampling frequency or the differences in the selected age groups. Abel, *et al.*

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[6] Predictable target is one where the step size and direction is not random (e.g. 10° to the right from the centre of fixation at a certain time interval)

[7] Unpredictable target is one where the target is randomly stepped from a range of amplitudes (5°, 10, 20° or 30°) to the right or left side from the centre at a certain time interval)

[8] Unpredictable time target is one where the step of the target is stable (i.e 10° in the horizontal direction to the right) but the time interval used is random.

(1983) used an infrared reflectance technique whereas Warabi, *et al.* (1984) and Moschner, *et al.* (1994) used electrooculagraphy. The difference between Warabi, *et al.* (1984) and Moschner, *et al.* (1994) was on the sampling frequency. Moschner used 200 Hz whereas Warabi, *et al.* used 100 Hz. Another difference between these two latter studies is the heterogeneous distribution of decades. The age range used by Warabi *et al.* (1984) for the young age group was "limited" until the second decade of life (16-26 years) whereas the one used by Moschner was extended up to the forth decade (18-43 years). Regarding the selection of the older group, two of those studies (Abel, *et al.* 1983; Warabi, *et al.* 1984) were similar. On the other hand, the older group used by Moschner, *et al.* (1994), was divided into two subgroups, younger seniors (75-79 years) and older seniors (80-93 years).

Hotson and Steinke (1988) reported an increase in latency to unpredictable timed target steps (3-15°) in vertical directions with ageing. In this study, a monocular Purkinje eye tracker was used. Similarly, another study on predictable larger vertical target steps (10-30°) using a magnetic search coil, showed similar results (Huaman and Sharpe 1993) indicating that latencies of vertical saccades are dependent on the effect of ageing but independent of the target type.

Despite the investigation on how ageing affects saccadic latency, there were some studies that also raised the question of directional specialization in terms of this parameter (Pirozzolo and Rayner, 1980; Huton and Palet, 1986; Pitt and Rawles, 1988; Munoz, *et al.* 1998; Hond, 2002; Constantinidis, *et al.* 2003).

Pitt and Rawles (1988) reported that latencies recorded in the nasal direction of the horizontal plane were longer compared to the ones in the temporal direction by 2.5 msecs. Munoz *et al* (1998) reported the same nasal versus temporal asymmetries in saccadic latencies with the exception of one of their different task conditions under investigation (pro-gap condition[9]). Interestingly, some studies revealed that this nasal versus temporal asymmetry was only found in the right-handed observers (Pirozzolo and Rayner, 1980; Huton and Palet, 1986).

In contrast, Honda (2002), using a scleral-reflectance technique, examined the nasal/temporal saccadic latency asymmetries in healthy observers. They suggested that there is no such latency asymmetry (nasal versus temporal). Similar results were also reported in a study with infrared oculography where 10° visually guided saccadic eye movements were recorded (Constadinidis, *et al.* 2003).

This literature review has revealed that there is only one study (Bono, *et al.* 1996) that has reported a directional effect on the saccadic latency in the vertical directions (UP versus DOWN). They revealed that the saccadic eye movements in the up direction had shorter reaction time compared to those made down.

2.1.4.1.2 Peak Velocity

Peak velocity (PV) is the maximum speed of a saccade. It has a directly proportional relationship with amplitude (i.e. with an increase of amplitude there is an increase of PV) but it is independent from duration. It is reported that the PV can vary between 350 –700 deg/sec. Small saccades show a relatively symmetrical velocity profile by reaching maximum velocities approximately half way with respect to the duration of the saccade in order for the acceleration and

[9] Pro-gap condition: during this condition the central fixation point disappears and after a gap period (200msecs) the eccentric target appears.

deceleration to have the same duration (Becker, 1991). There are several factors that influence saccadic peak velocities. One of those factors is the orbital direction (centrifugal or centripetal). It is reported that saccades, which start from the primary position (straight ahead gaze) and finish in an eccentric position (centrifugal) reach lower peak velocities and have longer durations than those returning from an eccentric position to the primary one (centripetal) (Collewijn, *et al.* 1988a; Becker, 1991). Another factor that can influence the measured value of PV is the sample size and the recording technique. It is reported that generally infrared methods give higher values than those measured by electrooculography (Boghen, *et al.* 1974). In 1975, Bahill, *et al.* reported that another factor that can influence peak velocities is muscular and mental fatigue (tiredness). They used this term in its broad sense, which included all those phenomena that contributed to impairment or loss of efficiency and skill. These phenomena may include frustration or boredom of performing a monotonous task as well as stress. In addition, Ciuffreda and Tannen (1995) suggested that saccadic peak velocities are slower in darkness by approximately 10% than those obtained during normal light conditions.

Several studies have also investigated the effect of ageing with regards to peak velocity and contradictory findings have been described. Some have reported significant ($p< 0.01$) decrease of peak velocity in the elderly for horizontal (Spooner, *et al.* 1998; Pitt and Rawles, 1988; Tedeschi, *et al.* 1989; Bono, *et al.* 1996; Fahle and Wegner 2000) and vertical directions (Hotson and Steinke 1988; Fahle and Wegner 2000). Some others studies have reported a significant decline in peak velocity but only observed in larger amplitudes (Warabi, et al. 1984; Sharpe and Zackon, 1987; Wilson, *et al.* 1993; Moschner and Baloh 1994). In contrast, others reported no consistent variation in peak velocity with senescence for either horizontal (Henriksson, *et al.* 1980; Abel, *et al.* 1983; Hotson and Steinke 1988; Munoz, *et al.* 1998; Shatig-Antonacci *et al.* 1999) or vertical directions (Huaman and Sharpe 1993). Nevertheless, Abel *et al.* (1983) reported that although there is no significant decline in saccadic velocities in the elderly (mean age 72 years) for angles greater than 30°, there is a small, non-significant change in overall velocities for amplitudes smaller than 30°. The different results across these studies can be attributed either to the different recording systems used or the different protocols (i.e. target step sizes, different age distribution in the observers).

Several studies have indicated that there is an influence of the target type in the results obtained on the effect of senescence in peak velocity mainly in the horizontal directions. Sharpe and Zackon (1987) found the slowing saccades were only significant in predictable targets ($p<0.05$) whereas Warabi, *et al.* (1984) identified this highly significant ($p<0.001$) slowing when both target time and amplitude were unpredictable. In contrast, Bono *et al.* (1996) showed significant negative correlation between peak velocity and age in both predictable and unpredictable target sequences. These results indicate no consistent dependency with target type.

The effect of ageing on the peak velocity of vertical saccades has not been as well documented as the horizontal one. In 1984, Wennmo, *et al.* using electrooculography reported that upward saccades were faster than downwards saccades but there was no significant slowing with senescence. Similar results were reported by Huaman and Sharpe (1993), although they used a different and more precise recording system (magnetic search coil) than the one used previously. In contrast, Hotson and Steinke (1988) found a significant reduction of peak velocity with ageing for 10 degrees saccades. This vertical slowing was observed to be equal in both directions (up and down).

Another element that has been studied in relation to saccadic peak velocities is the effect of direction. Several studies have reported that saccades in the temporal direction are faster compared to the nasal by approximately 20 degrees/seconds for saccadic amplitudes ranging from 10° to 50° (Robinson, 1964; Fricker and Sanders, 1975; Hallett and Adams, 1980; Collewijn, *et al.* 1988a; Becker, 1991; Fahle and Wegner 2000).

In contrast, several studies, where monocular eye movements were recorded using electroculography, have shown that saccades in the nasal direction were faster than in the temporal one (Boghen, *et al.* 1974; Bird and Leech, 1976; Miyoshi, *et al.* 1981; Becker 1991). In addition, Pitt and Rawles (1988) recorded 20° binocular saccadic eye movements using a bipolar recording of the corneo-retinal potential. They revealed that peak velocities in the nasal direction were faster by an average of 45.4 degrees/seconds compared to the temporal direction.

In addition, three studies, using magnetic search coil, have reported that upward movements reach higher peak velocities compared to those in the down direction (Yee, *et al.* 1985; Wennmo, *et al* 1984;Collewijn, *et al.* 1988b; Becker and Jurgens 1990). Despite their suggestions, Becker and Jurgens (1990) also reported that one of their ten subjects had faster downwards saccades compared to the upward ones. Two studies showed contradictory results to those mentioned previously (Hotson and Steinke, 1988; Huaman and Sharpe 1993). They reported no significantly different results between the vertical directions.

An additional comparison between the peak velocities of the horizontal and vertical saccades was made with contradictory results. A study that used magnetic search coil (Leigh *et al.* 1982) reported that there were no significant differences among the horizontal and vertical saccadic eye movements. Becker (1991) also reported that upward saccades on average were as fast as the horizontal ones. In contrast to this notion, Collewijn, *et al.* (1988b) reported that vertical saccades were slower compared to the horizontal ones except for amplitudes ranging from 60° to 70°.

2.1.4.1.3 Amplitude (or accuracy)

Amplitude is the measure of the size of a saccade. It is calculated by the absolute value of the subtraction between the start and end of a selected saccade. An interrelated parameter to amplitude is accuracy. The latter is defined as the difference between the eye position required by the target and that achieved by the saccade (Becker, 1991). Therefore a decrease in accuracy could result either from a systematic increase (overshoot) or a systematic decrease (undershoot) in amplitude.

Ciuffreda and Tannen (1995) reported that most naturally occurring saccades are less than 15 degrees in amplitude. It has also been reported that saccadic amplitude may differ when non-target objects appear at the same time as the target. This differentiation results in an increase of amplitude when those non-target objects appear on the far side of the actual target and a decrease of its size when those non-targets appear between the fixation point and the actual target (Coren and Hoening, 1972; Cohen and Ross, 1978; Becker, 1991). Deubel, *et al.* (1988) documented that this kind of modification (increase or decrease in amplitude) does not necessarily arise from well-defined objects that stand out against the background but also from patterns that show differences in texture and need a considerable amount of visual processing in order for them to be perceived.

These saccadic parameters (amplitude and accuracy) have also been studied in relation to senescence. Several studies have reported that there is no effect of ageing in accuracy (or amplitude) for both horizontal (Warabi, *et al.* 1984; Rosenhall, *et al.* 1987; Moschner and Baloh, 1994; Scialfa, *et al.* 1994; Abrams *et al.* 1998) and vertical directions (Hotson and Steinke 1988). In contrast, there are others who suggested that there is a significant decrease in accuracy (resulting from systematic decrease in amplitude) with ageing in both horizontal (Abel, *et al.* 1983; Sharpe and Zackon, 1987; Doig and Boylan, 1989; Tedeschi, *et al.* 1989; Olincy, *et al.* 1997) and vertical directions (Chamberlain, 1971; Huaman and Sharpe 1993). These discrepancies could be attributed in several parameters like the different recording systems, different sampling rates, the way each study defined the start- and end- of the saccadic eye movements, the type of the task, the age range and even the different statistical analysis.

Two studies using an electroculography technique (Warabi, *et al.* 1984; Moschner and Baloh, 1994) agreed on the fact that there was no significant difference in saccadic metrics between older and younger observers indicating that the majority of the elderly captured the target as accurately as the younger ones and suggested that this parameter might be spared of senescence. Moschner and Baloh (1994) also reported that on an individual basis the older subjects had higher inter-subject variability than the younger ones. A study using a video eye tracking technique (Scialfa, *et al.* 1994) reported a slight but non-significant ($p=0.259$) effect of ageing in accuracy. They also reported that the effect of eccentricity ($p<0.001$) and distractor type ($p<0.005$) was significant in the accuracy but both age groups were affected similarly. Rosenhall, *et al.* (1987) in a study with gaze angles of 20°, 40° and 60° and unpredictable time reported that the accuracy of saccadic eye movements was the same in all age groups. In addition, they reported that all observers executed one single normometric[10] saccade.

Sharpe and Zackon (1987) used an infrared limbus reflection oculography to record saccadic eye movements in different target types (predictable and unpredictable steps as well as unpredictable time targets). They showed that the elderly (mean age 77 years) had higher prevalence of hypometric[11] saccades for responses to both predictable and unpredictable targets. Thus, overall the older group of observers performed more saccades in order to reach the fixation target. Similar results were shown in other studies (Abel, *et al.* 1983; Tedeschi, *et al.* 1989; Scialfa *et al.* 1994).

Even though the effect of ageing on vertical saccadic accuracy or amplitude is not as well documented as the horizontal one there are also several studies concerning this matter. Chamberlain (1971) - using a hand perimeter to measure ocular rotations - suggested an existing highly significant restriction (ANOVA $p<0.001$) in upward gaze with advanced age but they did not indicate such an alteration in the downward one. A study with a magnetic search coil, thirty years later (Huaman and Sharpe 1993), affirmed the findings reported by Chamberlain (1971), regarding the up-gaze limitations in ageing. In contrast to Chamberlain's findings, they also identified a further reduction in the downward excursion. Furthermore they reported that there was a significant decline in

[10] Normometric (orthometric) saccade consists of a single-step, accurate movement and it occurs because the step and the pulse – controller signal – are equal.
[11] Hypometric or undershoot saccades are the ones where the gain of the actual eye movement is smaller than the desired one

accuracy in 10° down, 20° up and 30° both directions (up and down). This is also in contrast to Hotson and Steinke (1988), who used a monocular Purkinje image eye tracker and reported that there was no change in accuracy at target steps of 10° in the vertical directions. This difference may be attributed mainly to the different recording systems in each study.

To date, the effect of direction upon this saccadic parameter is not well documented. However, there are two studies that have reported saccadic amplitude asymmetry in the horizontal (Fahle and Wegner, 2000) and vertical directions (Huaman and Sharpe, 1993). Fahle and Wegner (2000) using an infrared technique reported that the gain[12] (relative amplitude) was decreased for the nasal hemifield compared to the temporal at target step of 30°. In addition, Huaman and Sharpe (1993) reported that individual young observers made significantly larger downward than upward saccadic eye movements.

2.1.4.1.4 Duration

Duration is namely the time that the eye movement lasts and increases as a function of amplitude. Duration and amplitude have a linear relationship over a wide range, which is given by: $D = D_0 + d\,A$ (where D = duration, A = amplitude, Do = the y-axis intercept of the D versus A line and d = the rate of duration increase per degree of amplitude) (Figure 2.1.4.1.4) (Becker 1991). This equation represents a model fitted to data (from different studies). Furthermore, Becker (1991) reported that the rate of duration *(d)* ranges from 2-3 msecs per degree of amplitude whereas the intercept D_0 has typically values 20-30 msecs (e.g.

[12] Gain is the percentage of the amplitude value achieved by the ratio of a primary saccade over the required amplitude. A gain equal to 1 is considered as accurate, less than 1 as hypometric and more that 1 as hypermetric.

Robinson, 1964; Baloh, *et al.* 1975; Collewijn, *et al.* 1988a). None of these studies have clearly indicated what the intercept D_0 represents. Our own hypothesis is that this value (D_0) might be interpreted as a rise time of isometric force in muscle activity (Robinson, 1964).

Baloh, *et al.* (1975) using electrooculography, suggested a constant linear relationship between duration and amplitudes up to 90 degrees in the horizontal directions. In addition, Collewijn, *et al.* (1988a) documented that one could observe a progressive increase in saccadic duration in amplitudes above 50 degrees. The method used in this particular study is a magnetic field-sensor coil. They also reported that a larger increase in duration was observed, as the eye approached the physical limits of orbital motility. Another factor that is also mentioned to give an accelerating rise of saccadic duration is the tendency of some people, when engaged in a series of large saccades, to produce a slow saccade (Becker 1991).

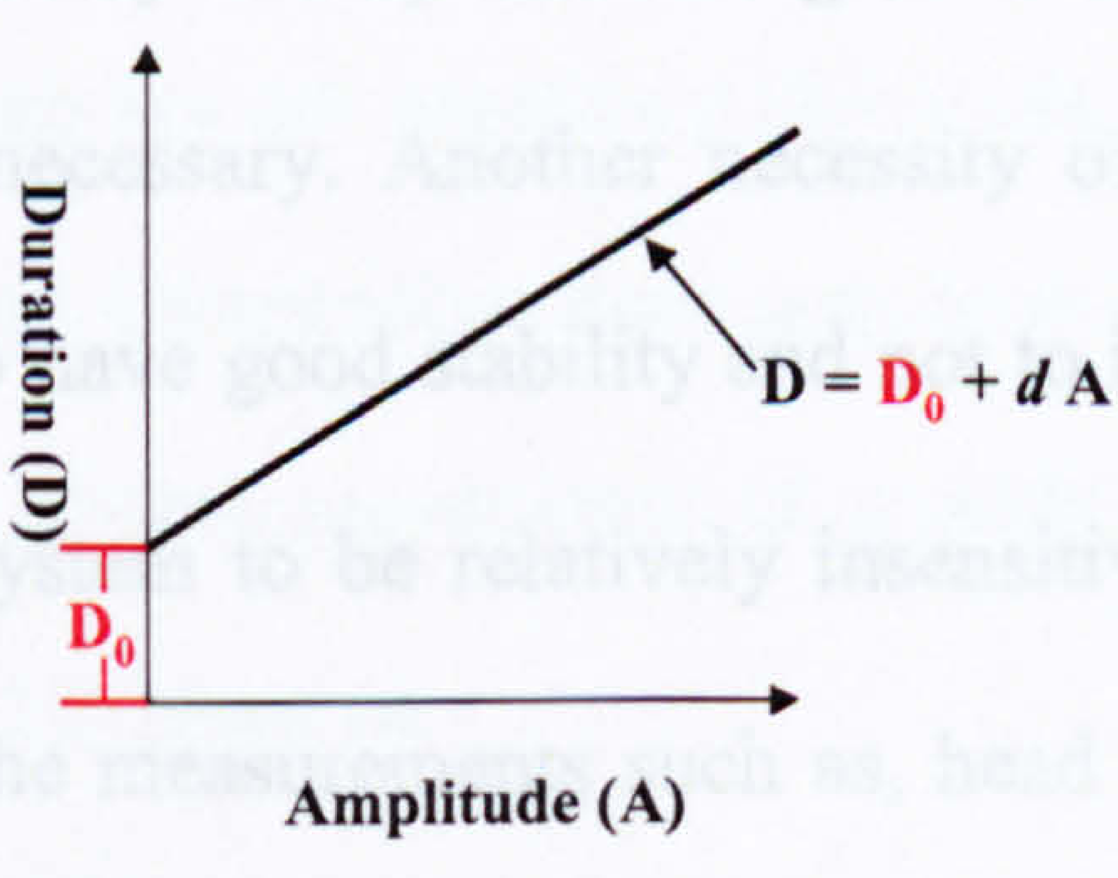


Figure 2.1.4.1.4: Schematic representation of the linear relationship between amplitude (A) and duration (D) where D = duration, A = amplitude, Do = the y-axis intercept of the D versus A line and *d* = the rate of duration increase per degree of amplitude.

Furthermore, most studies agree on an increase in saccadic duration with ageing (Spooner, *et al.* 1980; Warabi, *et al.* 1984; Munoz *et al.* 1998), with the exception of two studies (Abel, *et al.* 1983; Abrams, *et al.* 1998). Versino, *et al.*

(1992) using an electroculography also reported that the linear relationship between amplitude/duration was age-related. Thus saccadic duration was expected to slightly increase with senescence for given amplitudes. To our knowledge there is no established information on how direction (if any) has an effect on saccadic duration.

2.1.5 Methods of recording eye movements

There are several different methods that are commonly used for the assessment of eye movements in clinical research environment:

- Electrooculography (EOG)
- Magnetic Search Coil
- Infrared light emission (IR)

The most suitable recording system will depend on the nature and requirements of the experimental procedure. Collewijn *et al.* (1975) suggested that an ideal method should satisfy several requirements. Firstly, they suggested that a sufficient resolution, linearity and dynamic range, which will vary depending on the type of study, are necessary. Another necessity of a good eye movement recording technique is to have good stability and not to interfere with vision. It is also important for the system to be relatively insensitive to several factors that may have an effect on the measurements such as, head movements, illumination and ambient conditions, eyelid closure and any kind of electrical or electromyographical interference. The subject's comfort is also another important factor to take into account. The applicability of the method should be easy for the clinician and non-traumatic for the subject. The ultimate requirement that they mentioned is to have simultaneous recordings of horizontal, vertical and torsional eye movements in order to be able to record and investigate alterations in all the directions of gaze because some can be more informative than others (Collewijn, *et al.* 1975).

From the above as one can expect, every researcher needs to have an in-depth knowledge of all the current monitoring methods in order to choose the most appropriate one depending on their own requirements and limitations.

2.1.5.1. Electrooculography (EOG)

The function of this technique is based on the principal that the eyeball is an electric dipole and that there is a permanent potential difference between the cornea and the retina. Silver-chloride electrodes are attached to the temporal canthii of each eye for horizontal eye movements' recordings and to the upper and lower lid for vertical recordings. An eye movement is recorded as a change of the electric field between the nasal and the temporal bone (Ciuffreda and Tannen, 1995).

It is reported that this method is widely used in eye movements recordings in infant research due to the fact that EOG allows head movements thus head restrains during recordings are not necessary (Richards, 1990). Even though this technique is easy to set up, inexpensive, does not cause any kind of discomfort to the observer and it can assess movements of a wide range, there are several reasons why it is not used in practice.

Firstly, the electrodes and their leads are susceptible to several factors, such as facial and blink eye muscle action and eyelid interference, that make the EOG recordings less consistent. The system's resolution[13] is also low thus abnormal eye movements (jerk nystagmus, saccadic intrusions) may remain undetectable. In addition, the signal (corneo-retinal potential) is influenced by

[13] Resolution is the smallest interval measurable by an instrument.

changes in light adaptation making their measurements even more unreliable (Ciuffreda and Tannen, 1995). It is also prone to drift because it is highly dependent on the position of the electrodes, thus a frequent recalibration is required (Schlag, *et al.* 1983). Another limitation of this method is that it is not a reliable method for quantitative recordings of vertical saccades due to eyelid interference (Yee, *et al.* 1985).

2.1.5.2 Magnetic search coil

In 1963, a new method for recording eye movements – magnetic search coil – was firstly introduced by Robinson. This method is based on the current that is induced by the movement of a coil within a magnetic field. During the recording procedure the observer wears a coil in the form of a contact lens surrounded by a metallic wire. The observer's head is stabilized within a horizontal or a vertical magnetic field depending on the direction that the recordings are carried out (Robinson, 1963).

This method has been generally regarded as one of the most accurate methods for measuring eye movements because it can be extended in all three axes of eye rotation. It also has high temporal and spatial resolution that allows even micro-saccades to be studied (Robinson, 1963;Collewijn, *et al.* 1975; DiScenna, *et al.* 1995).

Despite the fact that magnetic search coil has been considered as the gold standard method for measuring accurate eye movements, recent studies have reported that search coils influence the metrics of saccadic eye movements (Frens and Van der Geest, 2001; Smeets and Hooge, 2003). Frens and Van de Steen (2001), using an infrared technique, reported that when both eyes wore coils, the saccadic durations increased (by 8%) and the saccadic velocities reduced (by 5%)

when compared to the measurement with no coils. In addition, Smeets and Hooge (2003) reported that the use of scleral coils decrease the precision of human responses therefore compromises the advantages of its technical precision. This suggestion was investigated by measuring eye movements with a video-based system while subjects were wearing search coils.

Other disadvantages of using magnetic search coils clinically are its invasive aspect that causes ocular discomfort and an instillation of anaesthetic eye drops is necessary. It is also very expensive and an experienced technician is needed when used in clinical practice.

2.1.5.3 Infrared light emission (IR)

A non-invasive and inexpensive technique, relative to the magnetic search coil, that is commonly used both in clinical and experimental environments is the infrared reflection technique. There are several different commercial eye trackers; two of them are available from Applied Space Laboratories (Model 200 and Reading Eye II) and one from Skalar Instruments (IRIS). The IRIS 6500 (Skalar Medical, Delft, The Netherlands) – which is the model used in this study – has nine emitting diodes and nine sensitive detectors. These emitters and detectors are positioned in the middle with respect to the horizontal axis of the iris and at a distance that can vary (1.5–2.5 cm). The infrared light from the diodes illuminates the nasal and temporal regions – this is then reflected and the detectors perceive that reflected light.

The output in the nasal region is calculated by the summation of the reflected light perceived from detectors one and two whereas the output in the temporal direction occurs when the reflected light of detectors eight and nine is summed. Consequently, the eye movement signal in the horizontal direction is calculated by the subtraction of the output signal in the nasal (detector 1 + 2) and temporal (detector 8 + 9) regions. For example, when the left eye turns to a temporal direction then the output received from the nasal side will be higher than the one in the temporal (output A > output B) (Figure 2.1.4.2.3). This occurs due to the increased reflectivity from the sclera (nasal region) and the reduced reflectivity of the dark iris (temporal region) whose area has now increased within the field of the sensor.

During vertical measurements, the output (infrared light) in the up region will be calculated by the sum of detectors two and three and the down region by the sum of detectors seven and eight. The total received eye movement signal in the vertical direction will be obtained by the subtraction of the outputs between the up and down regions [(detectors 2 + 3)-(detectors 7 + 8)]. This latter arrangement has been used in order to reduce the eyelid artefacts in the eye movement recordings (Reulen, *et al.* 1988).

One of the disadvantages of this method is the limited dynamic range; less than 30 degrees for horizontal movements and 20 degrees for vertical ones. This limitation in addition to a change in the pupil's diameter may sometimes cause discrepancies in recording eye movements larger than 30 degrees. Another problem that may appear in vertical recordings is the interference of the eyelid margins, but this matter may be solved by simply taping of the lids. In addition, head restraint during eye movement recordings is necessary which might not make it suitable for use with all subjects, for example very young children.

The advantages of this method are that it is non-invasive and inexpensive as well as very easy to use without interfering with the subject field of view. Its capability to measure a wide range of eye movements (smooth pursuit, saccades, vergence) also increases its usefulness in a clinical environment (Reulen, *et al.* 1988).

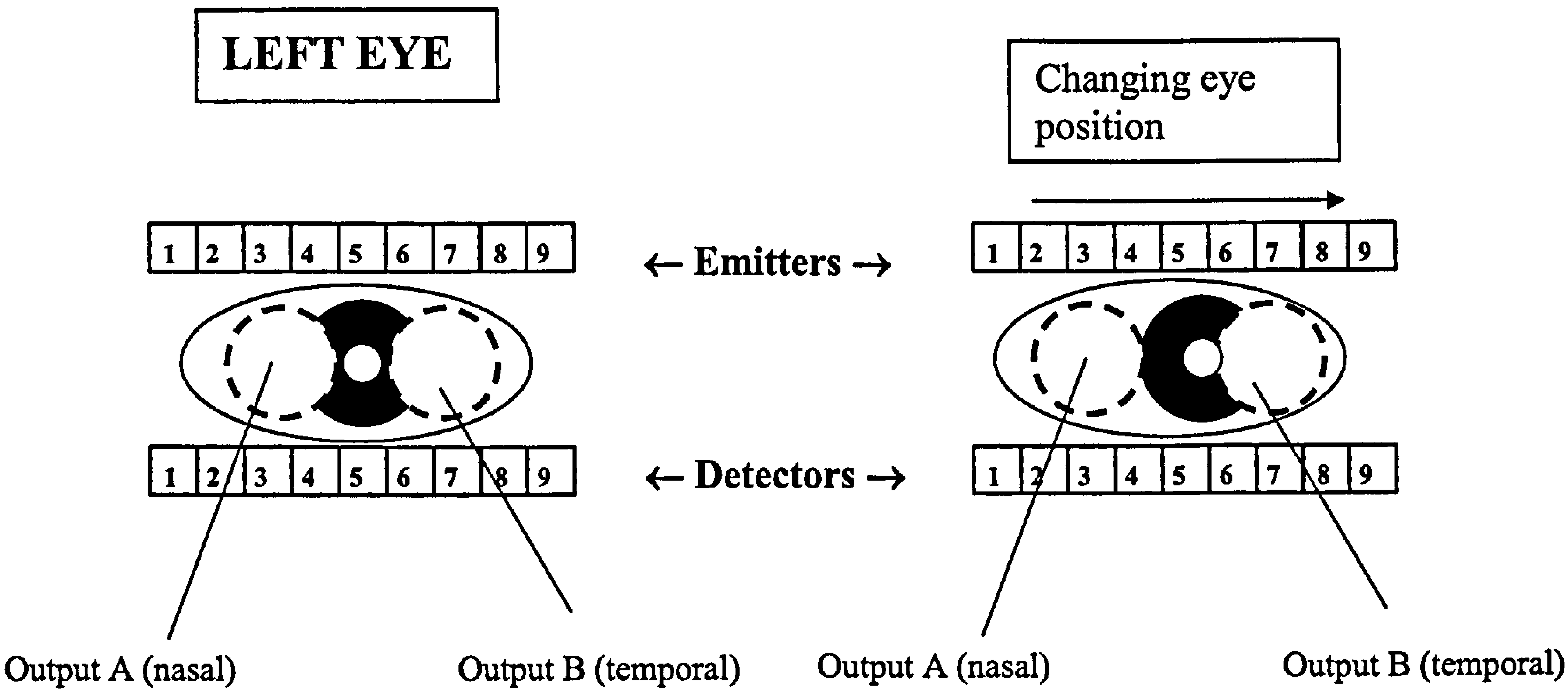


Figure 2.1.4.2.3: It shows that the output A and B are the illuminated areas of a left eye when the subject is looking straight ahead thus output A = output B. When there is a change in eye position towards the temporal side then output A > output B. The upper small squares represent the emitters whereas the lower ones are the detectors.

2.1.5.4 Video tracking

The development of video and image analysis technology generated another quantitative method of recording of eye movements. Some of the video tracking systems scans the image of the pupil because the position of the centre of the pupil represents the direction of gaze of the subject. Therefore, by measuring changes in the position of the pupil centre, eye movements can be monitored (Ciuffreda, 1995). Alternatively, the corneal reflex (first Purkinje image) can be tracked. This approach is based on the principle that the centre of the corneal curvature differs from the centre of the rotation of the globe therefore eye movements produce displacement of the corneal reflex (first Purkinje images).

Several studies have reported that one disadvantage of video tacking, either using the tracking pupil centre or corneal reflection, is the fact that its measurements can be influenced by lateral motion (Young and Sheena, 1975; Di Scenna, *et al.* 1995). Di Scenna, *et al.* (1995) specified that 1mm of lateral motion of the sensor relative to the eyes introduces an error of 5 degrees with pupil tracking and a 10 degrees with corneal reflections. In addition, Smeets, *et al.* (2003) reported that this method of recording eye movements is not able to measure three dimensional eye movements since the effect of changing orientation on the projection of the eye's image is measured instead of the direct measure of orientation. The temporal resolution of video eye trackers is also far worse than for other recording methods [50 Hz for the Cambridge Research System, 60 Hz for the ViewPoint eye tracker from Arrington Research, 120 Hz for the EL-MAR system 2020 from Downsview (Di Scenna, *et al.* 1995) and 250 Hz for Eyelink system from SR Research (Smeets and Hooge, 2003) compared to approximately 1000 Hz for the Skalar infrared system]. An advantage of this method for recording eye movements is the fact that is able to measure eye movements during natural activities such as walking and/ or sitting down without head restrains. Although prices are coming down this method still is more expensive than infrared eye trackers.

2.2 Anatomy

The speed and precision of eye movements depends on the unique properties and function of the extraocular muscles of the orbit (Spencer and Porter 1988;Porter, *et al.* 1995). Each eye consists of six extraocular muscles: four rectii [medial (MR), lateral (LR), superior (SR) and inferior (IR)] and two oblique [superior (SO) and inferior (IO)] (Figure 2.2.1.1).

Because of the anatomy of the extraocular muscles, eye movements can be made in several directions (horizontal, vertical and oblique) (Figure 2.2.1.2). Each one of these meridians requires different combinations of muscles – *horizontal*: MR (nasal/adduction) and LR (temporal/abduction) muscle respectively, *vertical*: up with both SR and IO and down with both IR and SO (Ciuffreda and Tannen 1995).

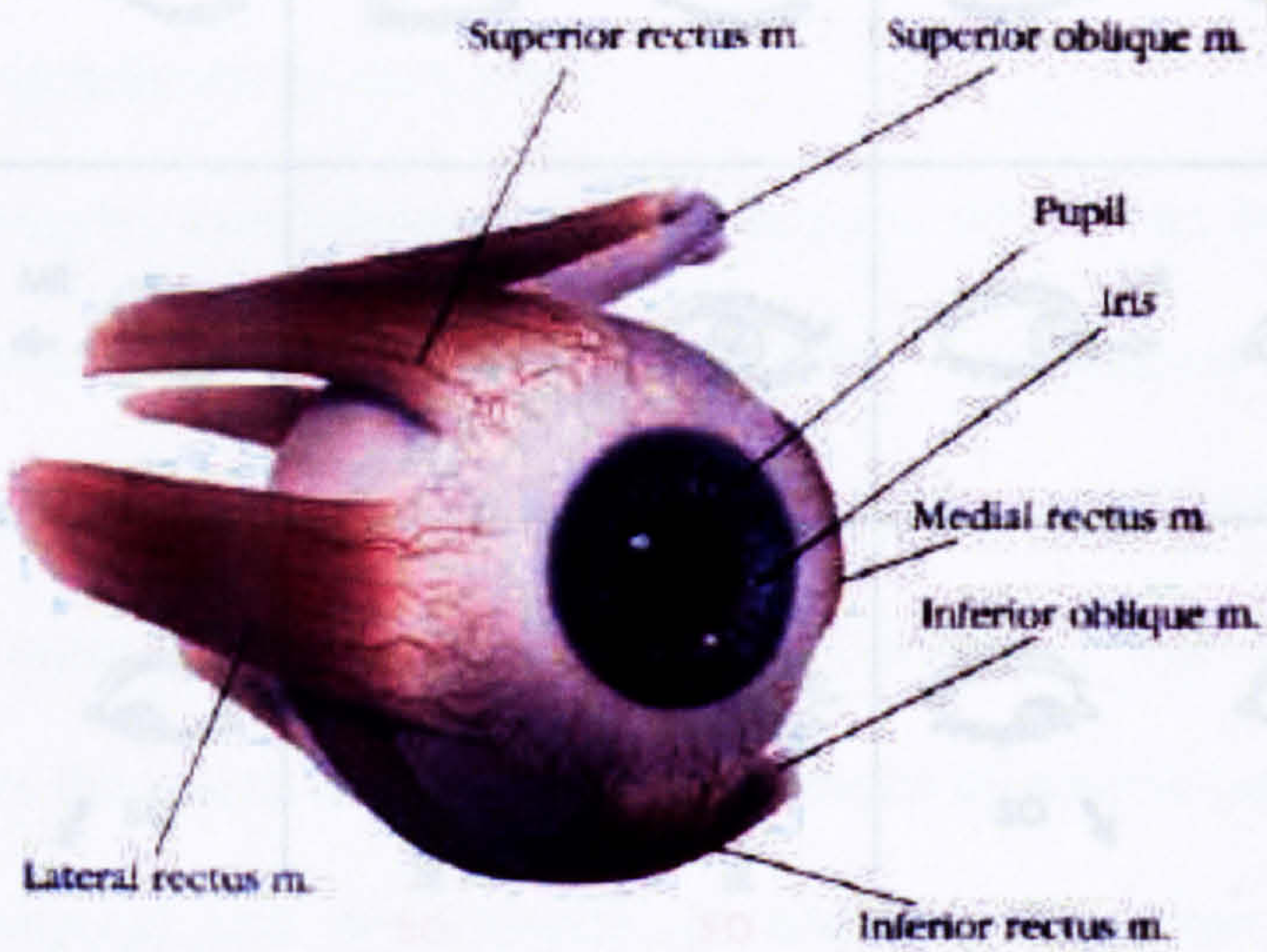


Figure 2.2.1.1:Illustration of all the extraocular muscles (http://www.waeyemd.org/anatomy-muscles.htm)

For a more clinical understanding of these individual actions of the extraocular muscles, there are several important aspects that should be mentioned: such as the anatomy of the orbit, the insertion, origin and innervation of each extraocular muscle. The four rectii muscles come from deep within the posterior part of the orbit and are attached to the sclera anterior to the equator and near the cornea. The two oblique muscles approach the globe anteriorly at the medial side of the orbit and continue obliquely and laterally to insert on the sclera posterior to the equator on the temporal part of the globe. The four rectii muscles and the superior oblique arise from the region of annulus of Zinn that is located at apex of the orbital pyramid, where their origins are arranged in a more circular fashion. The inferior oblique arises from the medial orbital wall (Porter, *et al.* 1995; Von Noorden, 1995).

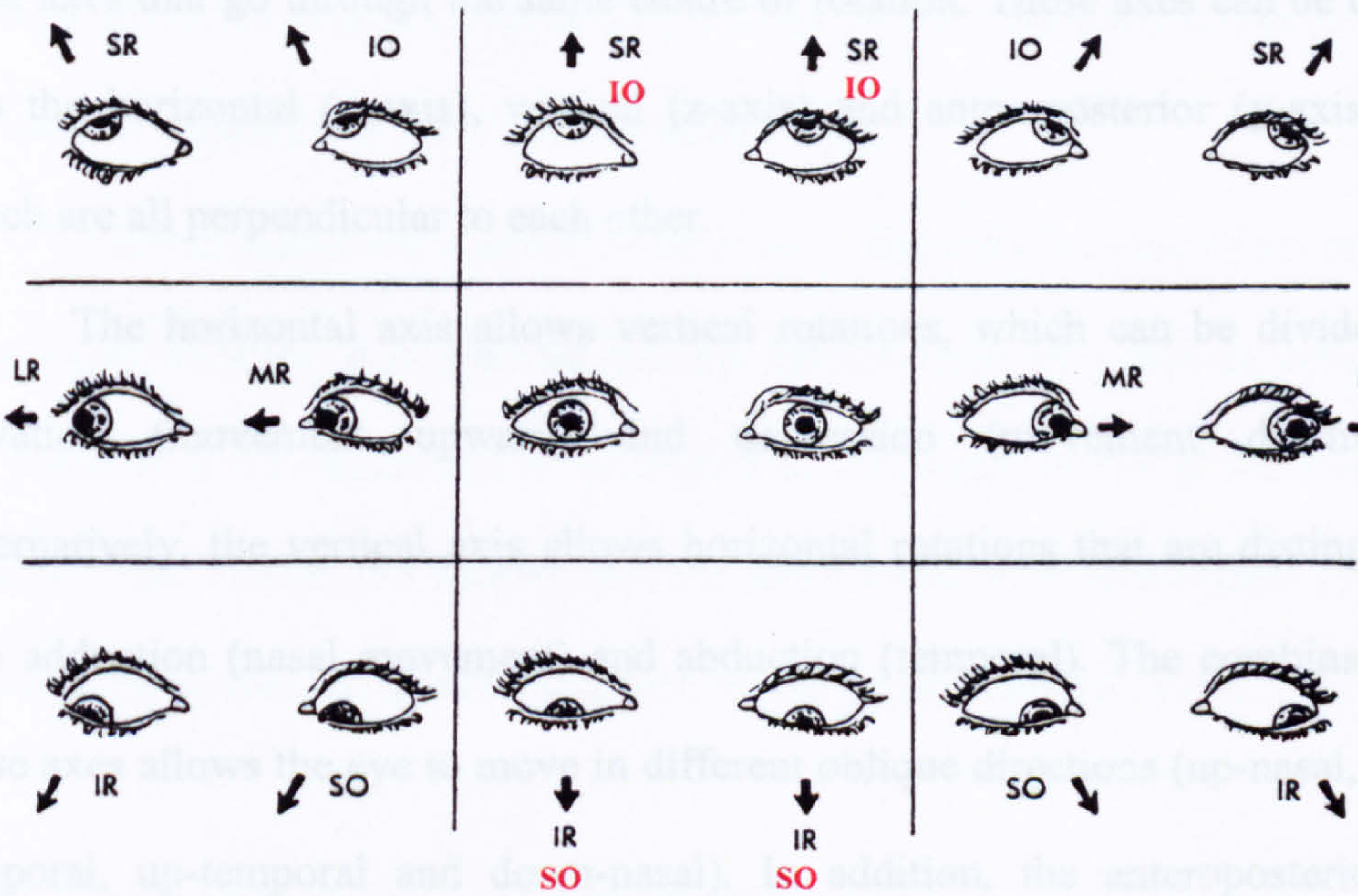


Figure 2.2.1.2: The nine diagnostic positions of gaze involving the six eye muscles: Superior Rectus (SR), Inferior Oblique (IO), Lateral Rectus (LR), Medial Rectus (MR), Inferior Rectus (IR) and Superior Oblique (SO) (as modified from Ciuffreda, 1995).

The medial, inferior rectus and the inferior oblique muscles are innervated via the inferior division of the oculomotor nerve (cranial nerve III) whereas the superior rectus is innervated via the superior division. In addition, the abducens nerve (cranial nerve VI) supplies the lateral rectus and the trochlear nerve (cranial nerve IV) innervates the superior oblique muscle. All extraocular muscles are supplied by the lateral and medial muscular branches of the ophthalmic artery (Porter, *et al.* 1995; Von Noorden, 1995).

2.2.1 *Action of extraocular muscles*

Another important aspect of ocular motility is the action of each extraocular muscle and the basic laws of kinematics that they obey during eye movements.

The globe (eye), which if we assume to be a sphere, can rotate around three axes that go through the same centre of rotation. These axes can be divided into the horizontal (x-axis), vertical (z-axis) and anteroposterior (y-axis) axis, which are all perpendicular to each other.

The horizontal axis allows vertical rotations, which can be divided into elevation (movement upward) and depression (movement downwards). Alternatively, the vertical axis allows horizontal rotations that are distinguished into adduction (nasal movement) and abduction (temporal). The combination of these axes allows the eye to move in different oblique directions (up-nasal, down-temporal, up-temporal and down-nasal). In addition, the anteroposterior axis contributes to movements known as cycloductions. These movements can be separated into excycloduction, which is the outward rotation of the globe, and incycloduction, as the inward rotation (Ciuffreda and Tannen 1995; Von Noorden 1995).

Each extraocular muscle acts differently with some of them having simpler movements than others. The horizontal rectii muscles (LR and MR) are responsible for the pure rotation around the vertical axis, producing abductions/temporal (LR) and adductions/nasal (MR). On the other hand, the vertical rectii muscles (SR and IR) have a more complicated action due to the angle (23°) that their direction of action makes with the y-axis. Therefore, the superior rectus produces an elevation as well as an incycloduction of the eye. As the horizontal angle of rotation increases and reaches 23° then the component of cycloduction deceases to zero and the superior rectus becomes a pure elevator muscle. Similarly, the oblique muscles (SO and IO) also have a more complex action. The inferior oblique forms an angle with the median plane (y-axis) of 54° and causes an excycloduction and elevation of the eye. The IO becomes a pure elevator when the degree of adduction reaches 54° or a pure excycloductor when the level of abduction is 36° (Von Noorden 1995).

Another important element to consider is the effectiveness of action of the extraocular muscles. It is reported that the effectiveness of a muscle depends on the position of its attachment with respect to the centre of the globe and on its volume. The heavier the muscle and the more anterior its attachment (with the centre of the globe) the greater its effectiveness (Von Noorden 1995).

2.2.2 Basic laws of oculomotor kinematics

There are many different theories that have been used to describe the general concepts of oculomotor system. These include: (1) Listing's law, (2) Donder's law, (3) Sherrington's law and (4) Hering's law.

Listing's law suggests that when the line of fixation is brought from a primary (when looking straight ahead) to any other position, the angle of false torsion in this second position is the same as if the eye had arrived at it by rotation about an axis (Listing's plane) perpendicular to the plane containing the initial and final positions of fixation. Listing's plane is an equatorial plane defined by the centre of rotation and the equator of the globe when the eye is looking straight ahead (primary position). In addition, Donder's law states that this single rotation of the eye about one axis is always the same regardless of the way in which the eye reached the new position (Von Noorden, 1995; Ciuffreda and Tannen 1995).

Two other laws, which are important in interpreting the results of monocular and binocular eye movement testing, are those of reciprocal and equal innervation respectively. According to the Sherrington law of reciprocal innervation, when an agonist, which is the muscle that produces a movement, contracts then a simultaneous impulse of relaxation is received by its antagonist. For example when the right eye moves to a temporal direction, the LR (agonist) contracts whereas the MR (ipsilateral antagonist) of the same eye relaxes. This law is essential during the testing of weakness in one or more muscles in a single eye (Kanski, 1999).

The notion that ocular eye movements between a pair of eyes are well established and documented. Hence, Hering's law of equal innervation states that when an impulse for contraction and/or relaxation is sent out to a specific muscle then an equal impulse is generated to the corresponding muscle in the fellow eye that allows movements in the same field of gaze. These are known as yoked muscles. For example the LR of the right eye and the MR of the left eye are yoked muscles and therefore when one looks to the temporal direction then this set of muscles will be equally innervated.

2.3 Neurology of eye movements

Following a brief analysis on the anatomy of eye movements, a concise overview of the major neuroanatomic structures involved in the generation of eye movements and more specifically in saccades, is necessary.

In the last few years, substantial progress has been made in understanding the neurology of eye movements. The use of sophisticated techniques like transcranial magnetic stimulation (TMS), positron emission tomography (PET) and functional magnetic resonance (MRI) have helped to better understand the brain areas involved in the generation of eye movements (Pierrot-Deseilligny, et al 1995; Carter and Zee, 1997; Leigh and Zee, 1999; Gaymard and Pierrot, 1999).

Different brain areas are involved in the generation of smooth pursuits and saccadic eye movements. The middle temporal (MT) and the median superior temporal (MST) regions, which are located in the temporal lobe (in monkeys), play a crucial role in the generation of smooth pursuit eye movements (Figure 2.3.1). The transmition of the neuronal signal from the MT and the MST can be executed by two different pathways, either directly to the dorsolateral pontine nucleus or indirectly via the frontal pursuit region within the frontal eye fields before reaching the cerebellum. The cerebellum provides the final processing of the motor command, which is executed by both the vestibular nucleus and the paramedian pontine reticular formation (PPRF) (Figure 2.3.1) (Gaymard and Pierrot 1999).

Leigh and Zee (1999) suggested that the neural control aspect of saccadic eye movements could be divided into two levels; lower and higher level control processes. The lower-level control process, involves the actual generation of the pulse-step signal by two different types of neurons (burst and omnipause) (Ciuffreda and Tannen, 1995; Leigh and Zee 1999). The pulse corresponds to the signal obtained by the burst neurons that commands the eye to overcome the viscous resistance of the globe and the orbital contents and move the eye rapidly into a new position. When this movement is finished then the step signal generated by the omnipause neurons, takes over and commands the eye to overcome the elastic restoring forces of the eye and retain the eye in that new position (Ciuffreda and Tannen, 1995; Leigh and Zee 1999). Hence, an accurate saccadic eye movement is produced by the perfect synchronization between the pulse and the step (Leigh and Zee 1999).

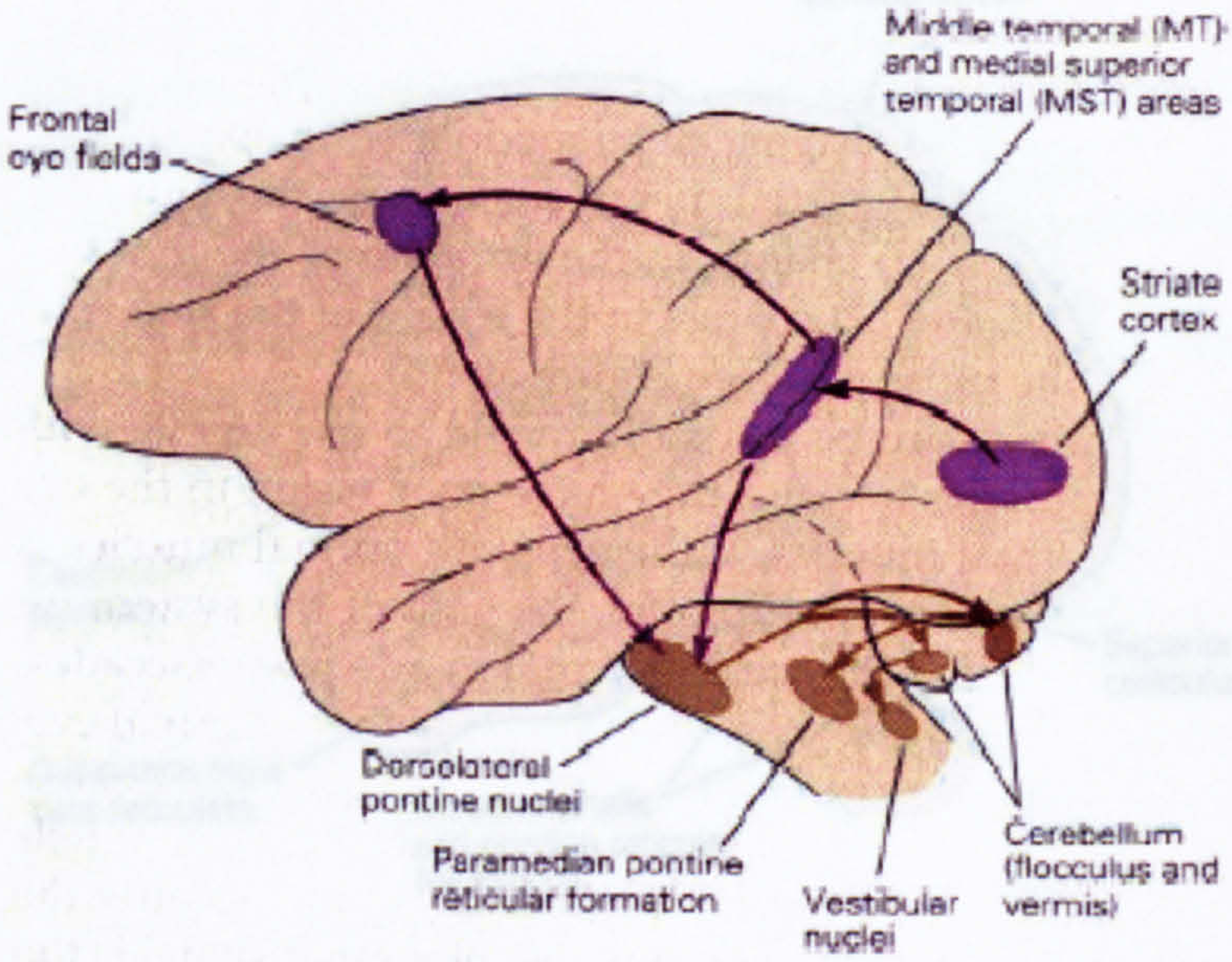


Figure 2.3.1: A map of the brain with the areas and the different pathways involved in the generation of smooth pursuit eye movements (http://brain.phgy.queensu.ca retrieved on November 2003).

The higher-level control involves several different brain areas that are involved in the generation of saccades (frontal eye field, supplementary eye field, parietal eye field, superior colliculus, brainstem) (Pierrot- Deseillingny, *et al.* 1995; Averbuch-Heller and Leigh, 1996; Carter and Zee, 1997; Leigh and Zee 1999; Gaymard and Pierrot 1999). Pierrot-Deseilligny, *et al.* (1995) reported that the frontal eye field is responsible for the intentional exploration of the visual environment whereas the parietal eye field is involved during a reflexive exploration of the visual scene. Gaymard and Pierrot-Deseilligny (1999) suggested that the role of the supplementary eye field in the generation of saccades is poorly understood. They reported that evidence shows that it has an involvement in the motor programming of repeated saccadic task but it does not appear to be a primary ocular motor area in the generation of saccades as is the case with the frontal eye field.

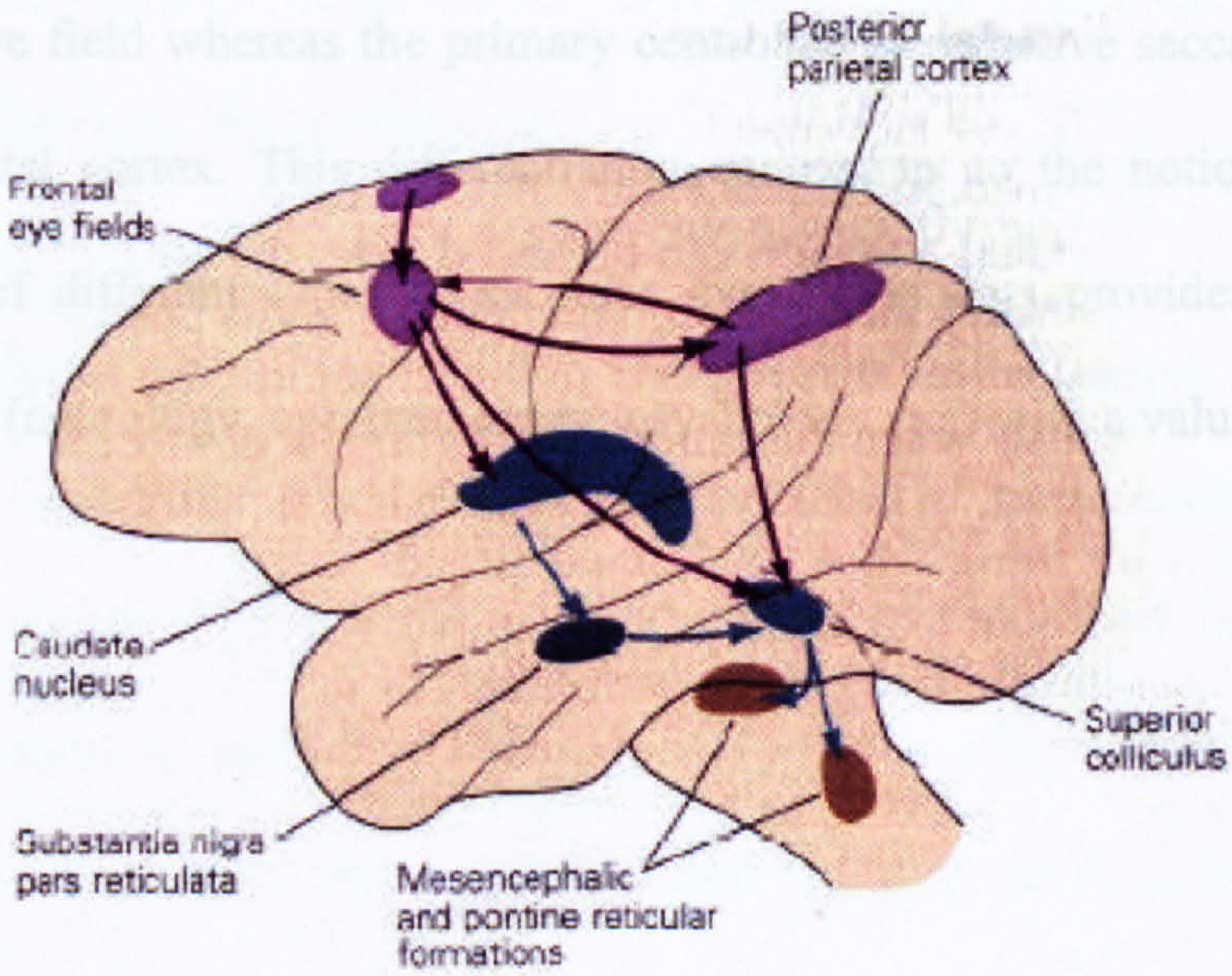


Figure 2.3.2: A map of the brain with the areas and the different pathways involved in the generation of saccadic eye movements (http://brain.phgy.queensu.ca retrieved on November 2003).

During the generation of saccadic eye movements, the superior colliculus receives direct projections from different cortical areas (frontal and parietal eye field). Through reciprocal connections it provides the motor command to the burst neurons in the paramedian pontine reticular formation, which is important for the generation of horizontal eye movements. Superior colliculus also triggers the command to the omnipause neurons to hold the eye steady after the saccadic eye movement is ceased (Pierrot- Deseillingny, *et al.* 1995; Averbuch-Heller and Zee, 1996; Leigh and Zee, 1999). In addition, the brainstem that involves the mesencephalic and pontine reticular formation is considered to be the generator of saccadic eye movements (Figure 2.3.2).

Finally, Carter, *et al.* (1997) reported that different brain areas are involved in the control of several types of saccadic eye movements. They suggested that voluntary visually-guided saccades are controlled by the frontal and parietal eye field whereas the primary controller of reflexive saccades is the posterior parietal cortex. This differentiation contributes to the notion that the investigation of different types of saccadic eye movements provides different research fields (neurology, ophthalmology, psychology etc.) with a valuable tool.

CHAPTER 3:

Preliminary studies

Several preliminary studies were made in order to set up the most appropriate protocol for our experiments. Those preliminary studies consisted of:

1. Establishing the sampling rate.
2. Investigating the linearity range of our system.
3. Designing a pilot study with a small number of observers in order to decide the appropriate step size for the experimental procedure.

Certain aspects of experimental methodology (i.e. eye movements monitoring apparatus, recording system, data processing) will be repeated throughout the Chapters of this thesis therefore they will be described here in more detail for future reference.

3.1 Sampling rate

3.1.1 Purpose

The purpose of this preliminary study is to establish the appropriate sampling rate for eye movement recordings. Prior to any data collection this selection is important due to the fact that during an over-sampled recording one will obtain a more detailed description of the event with more noise but without gaining any further information. In contrast, during an under-sampled recording, there is a higher possibility of missing the actual event.

3.1.2 Methods

3.1.2.1 Stimulus

The stimulus used in this study was a red LED target that was placed on a rotatable bar with a fixed protractor (Figure 3.1.2.1.1). This bar could be set in different axes: horizontal (180°), vertical (90°) and oblique (45°-135°).

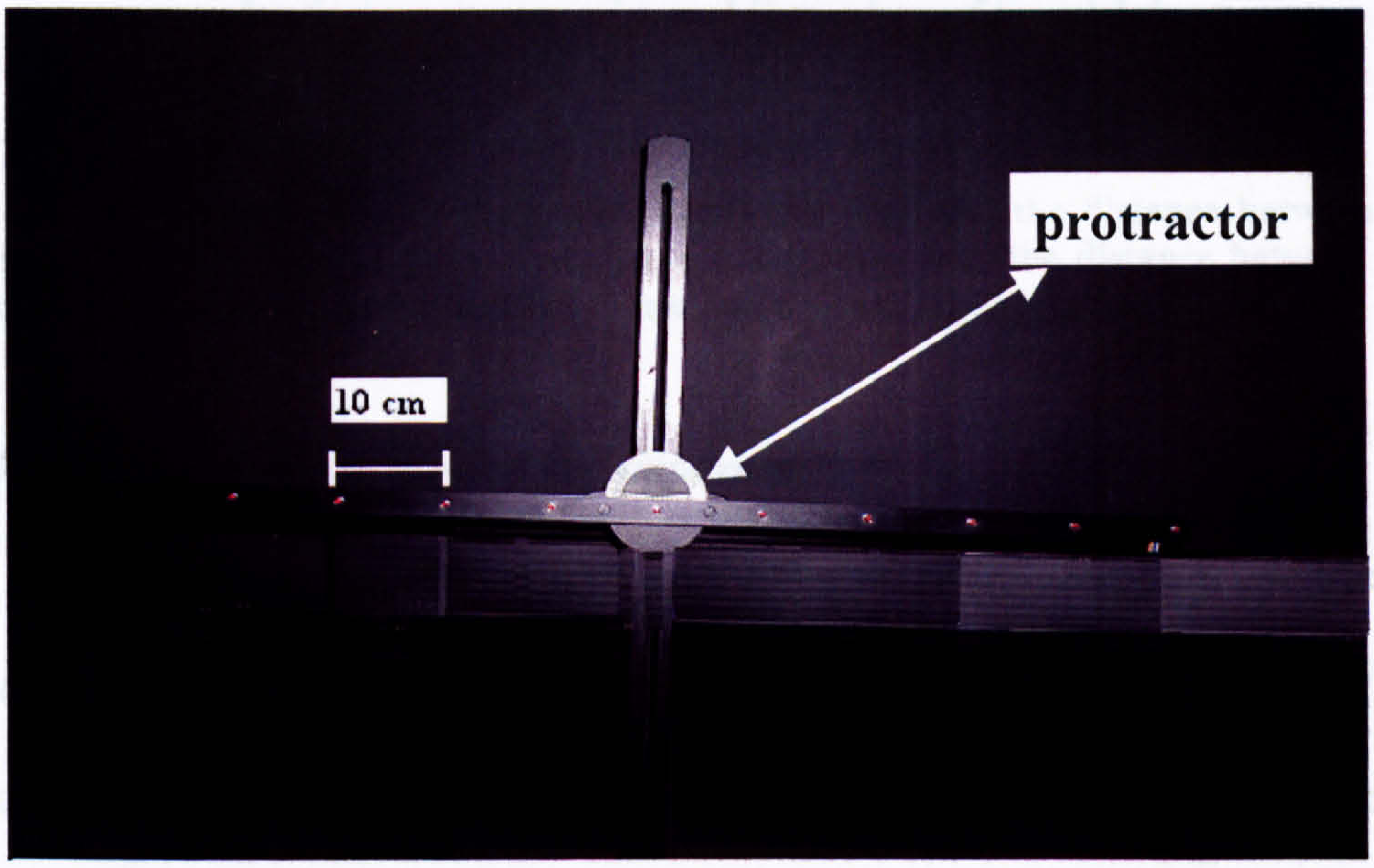


Figure 3.1.2.1.1: The stimulus used in this pilot experiment consists of LEDs fitted on a bar that could be rotated in different directions (45°- 90°- 135°- 180°) and it could also be adjusted in the appropriate height so the subject was fixating in the mid point of the bar when looking straight ahead. The distance between two LEDs (dx) was 10 cm.

The distance between the observer and stimulus (do: 114 cm) as well as between two LED lights (dx: 10 cm) were selected in order to establish 5° incremental steps. This arrangement subtended an eccentric range up to 20° (0° - 5° - 10° - 15° - 20°) (Figure 3.1.2.1.2).

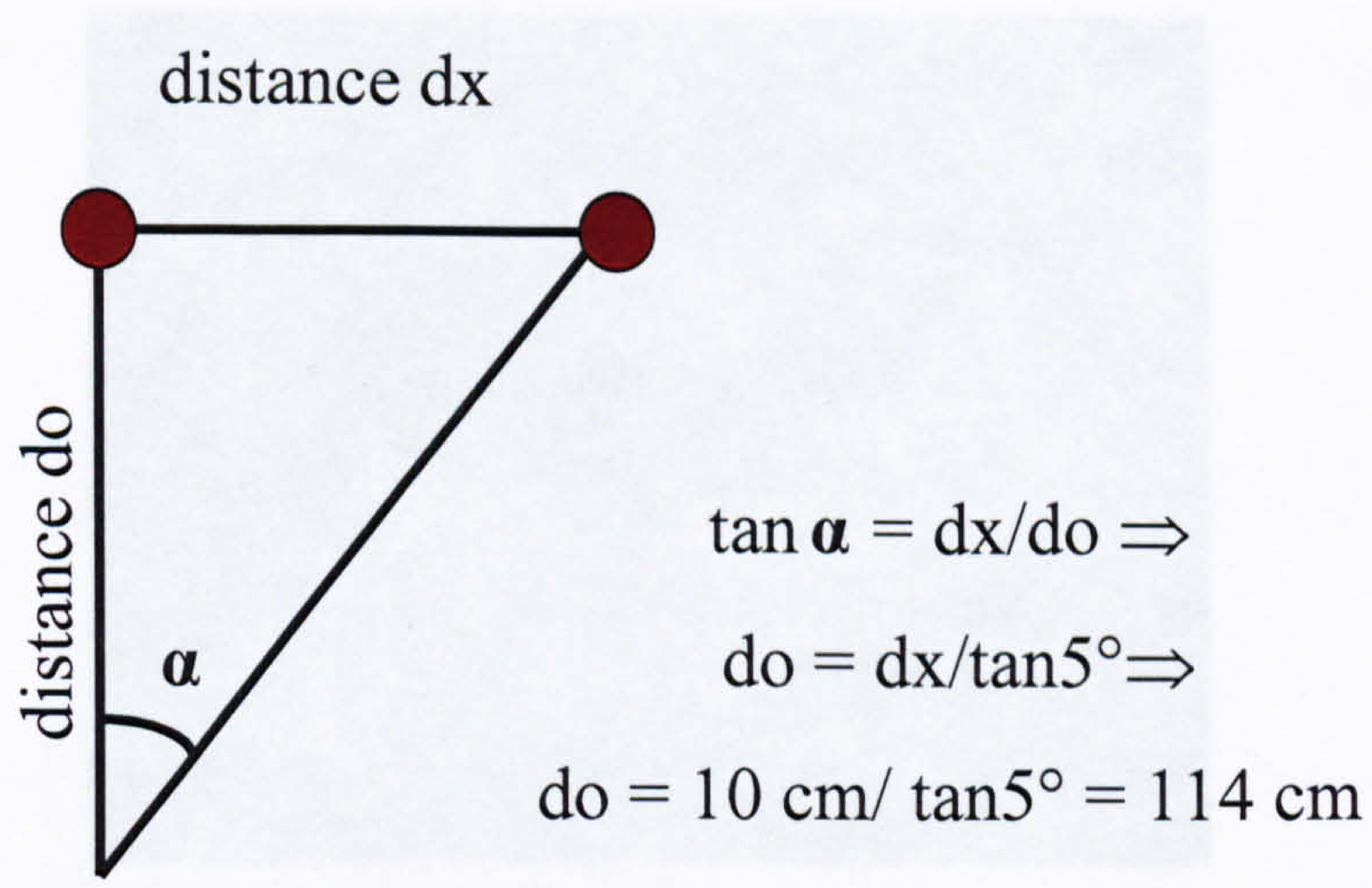


Figure 3.1.2.1.2: A schematic diagram that shows the way that the distance between the observer and the stimulus (do) was calculated, considering that the distance between two LEDs (dx) was 10 cm and that we wanted to subtend a visual angle (α) of 5°.

3.1.2.2 Eye movement monitoring apparatus

The apparatus used in this pilot experiment is an infrared light eye tracker (IRIS 6500), which is a non-invasive method for recording eye movement. This method is based on the reflection of infrared radiation by the iris-sclera boundary of the eye (Skalar Medical, Delft, The Netherlands). This system includes a lightweight head frame and two eye sensors – one for each eye – that are connected to a control panel through cables (Figure 3.1.2.2.1). Each sensor consists of nine emitting diodes (Siemens LD 269) and nine photosensitive detectors (Siemens BPX 69) (see chapter 1/ Figure 1.5.3). The maximum IR-light emission of the LEDs is at a wavelength of 950 nm and the optimal sensitivity of the detectors is at 850 nm (Reulen, *et al.*, 1988).

This eye tracker can be adapted to record either binocular or monocular horizontal and/or vertical eye movements. According to the manufacturers the field of view during a recording is limited to 30 degrees in the horizontal meridian and about 20 degrees in the vertical direction (Skalar manual).

Figure 3.1.2.2.1: IRIS 6500 infrared eye tracker consists of two sensors - one for each eye - fitted on a lightweight headset and are connected to the control panel.

A fundamental factor for obtaining reliable measurements is the optimal adjustment of the sensors. Therefore, the head of the subject was stabilized with a chinrest to eliminate the influence of movement during the recordings. While the subject is asked to fix on an object straight ahead, the experimenter, who approaches the subject from the front, adjusts firstly the height of the sensors in order to minimize the blockage of the target and then places the sensors in order for the white markers to coincide with the middle point of the iris (Figure 3.1.2.2.2). The experimenter used the subject's inner canthus as an additional reference point in order to set the sensor in such a way that its border overlapped to the inner canthus as indicated in Figure 3.1.2.2.3a.

Following these adjustments, the experimenter also approaches the subject from the temporal side and move the sensors in/out in order for the distance (z) between the eye and the sensor to be approximately 1.5 – 2.5 cm. This distance z might change if the subject has long eyelashes. Another necessary adjustment relates to the positioning of the sensor in a way that the imaginary projection of the emitter and the detector would fall in the posterior part of the eye (Figure 3.1.2.2.3b).

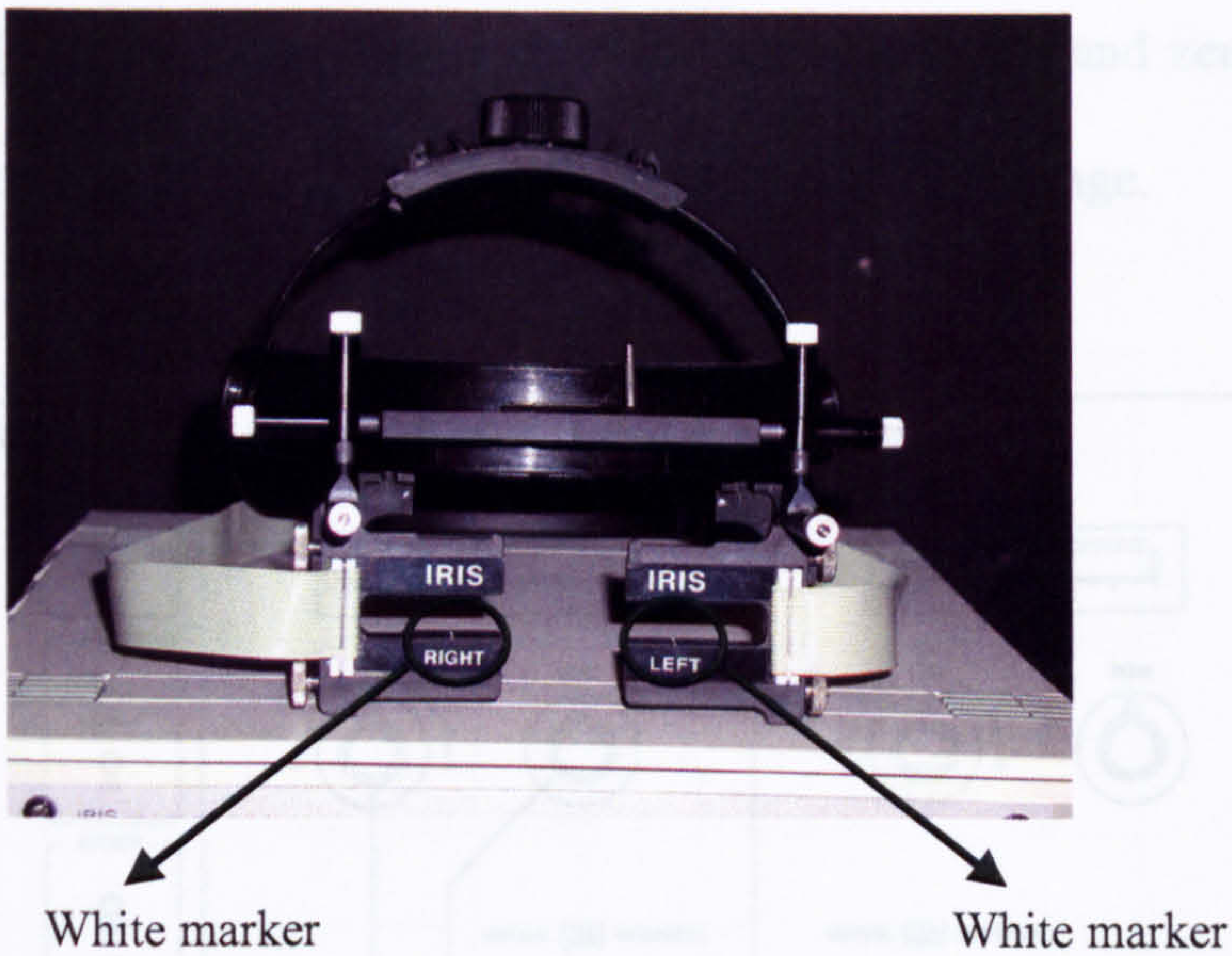


Figure 3.1.2.2.2: Front picture of the sensors fitted on the headset showing the white markers that are used as a reference point for an appropriate set up of the eye tracker.

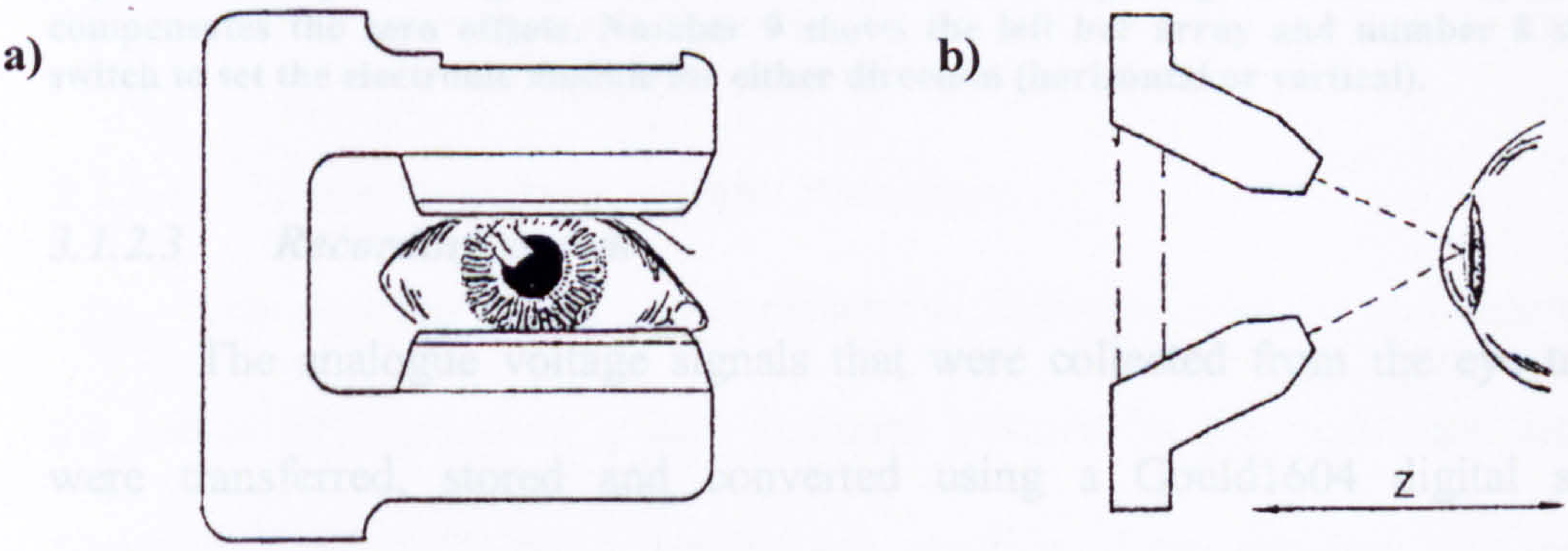


Figure 3.1.2.2.3: (a) The horizontal adjustment of the sensors in relation to the eye. (b) A schematic diagram that represents the side view of the sensor and it shows distance z, which expresses the distance between the eye and the sensor (as adapted from Instruction manual IRIS).

Generally, adjustments in the setting should be made until the LED bar indicator (9) on the front panel (Figure 3.1.2.2.4) will be in the centre and show a symmetrical signal when the eye is moving to the left and right. In addition, during all the adjustments described above, the rotary gain (6) and zero (7) that appear on the control panel were fixed in the midpoint of their range.

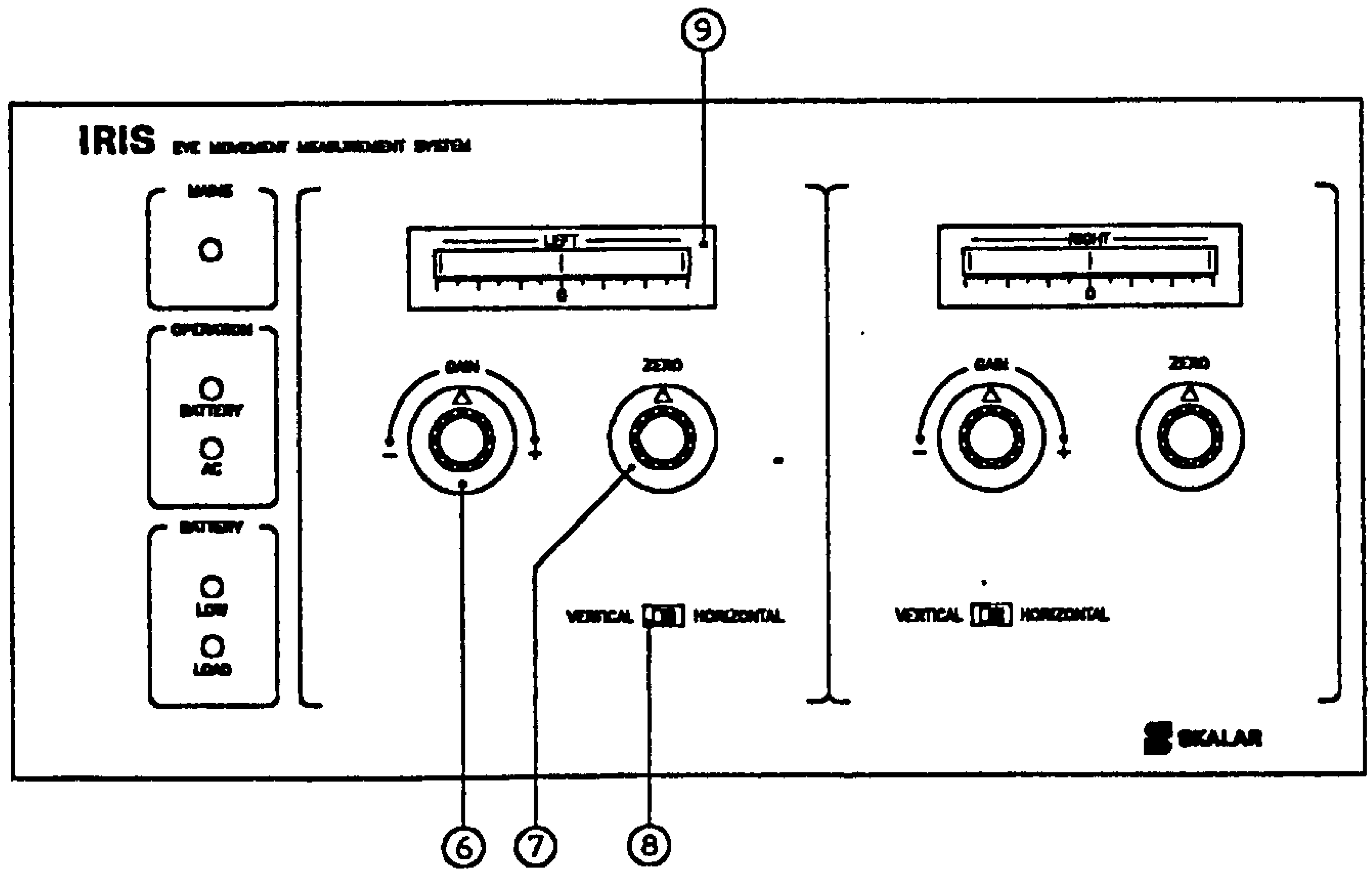


Figure 3.1.2.2.4: The front panel where there are two adjust buttons, a rotary gain (6) that adjusts the output voltage and thus the desired measuring range and the rotary zero that compensates the zero offsets. Number 9 shows the left bar array and number 8 shows a switch to set the electronic module for either direction (horizontal or vertical).

3.1.2.3 Recording system

The analogue voltage signals that were collected from the eye tracker, were transferred, stored and converted using a Gould1604 digital storage oscilloscope. Subsequently, data were transferred via an IEEE488 interface bus to a PC for analysis.

The screen of the oscilloscope consisted of 1024 points in the horizontal axis (10 divisions) and 240 points (8 divisions) in the vertical axis (Figure 3.1.2.3). In our experiment, the horizontal axis showed the time that the eye movement occurred whereas the vertical axis showed the step size of the eye movement in voltage. By adjusting the oscilloscope's settings we could change the scale of each of these axis independently. During the recording session, two traces were displayed on the screen; one corresponded to the eye position and the second to the stimulus.

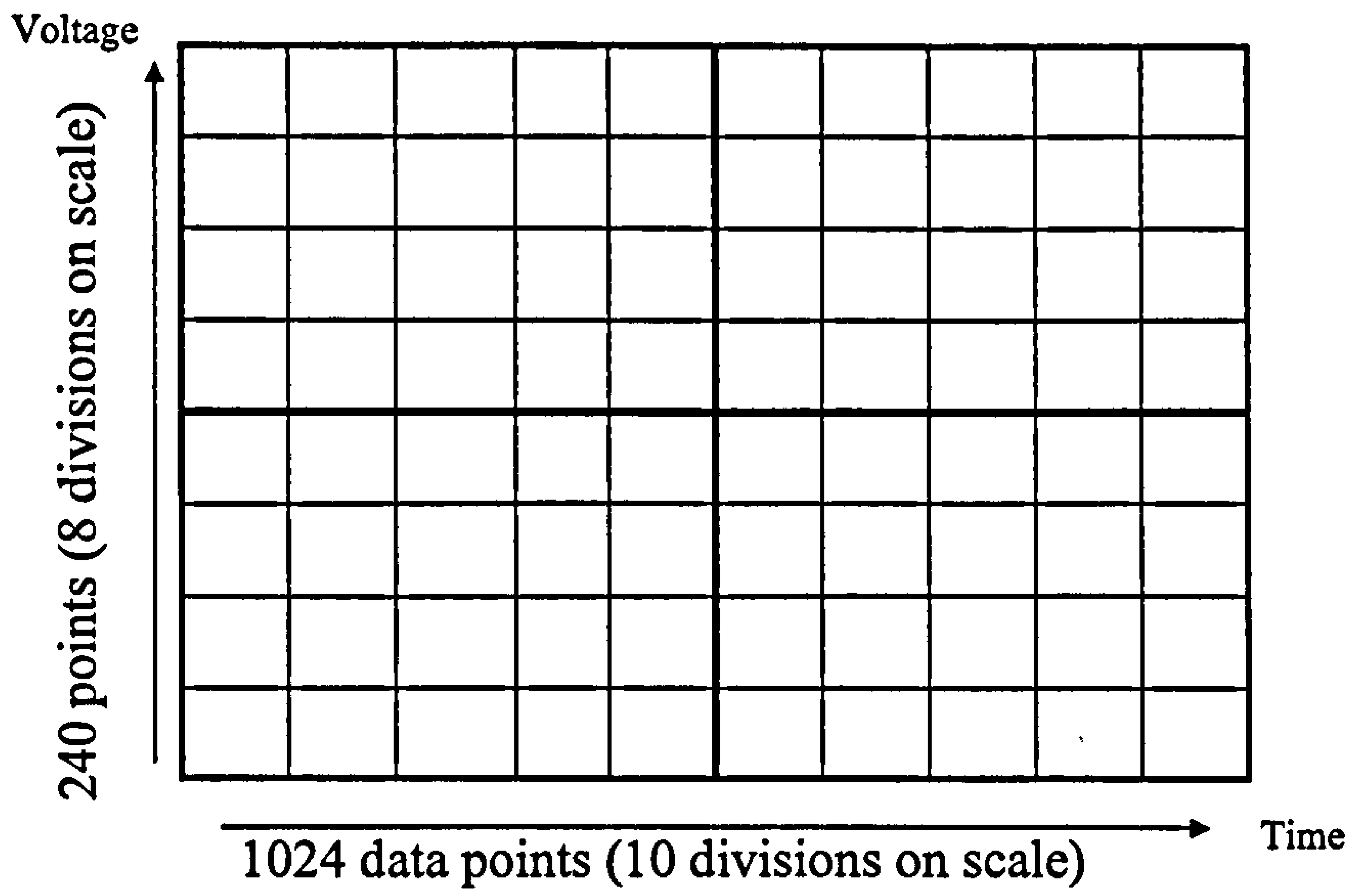


Figure 3.1.2.3: A schematic representation of the oscilloscope's screen used in this study. The horizontal axis expresses time and it is separated in 10 divisions whereas the vertical axis expresses voltage and is separated in 8 divisions.

3.1.2.4 Observers/ Experimental Procedure

One observer was asked to perform a single saccadic eye movement from the centre of fixation to a 20° eccentric position in the horizontal temporal direction. During this procedure the eye position of the observer was recorded under different sampling rates (time scales).

Figure 3.1.2.4 represents the position profile (left column) and the velocity profile (right column) of the 20° saccade under different sampling rates [(a) 2048 Hz, (b) 1024Hz, (c) 512Hz, (d) 204.8Hz, (e) 102.4Hz].

A visual inspection of Figure 3.1.2.4 reveals that the most appropriate sampling rate would be either 512 Hz or 204.8Hz. Figure 3.1.2.4 (a, b) shows the effect of an over-sampled eye movement recording where there is a lot of noise without any additional information of the actual event. In addition, Figure 3.1.2.4 (e) shows an example of an under-sampled recording where the actual saccadic eye movement has been missed.

From this set of data, we decided that the most appropriate sampling rate for the experimental recordings with this recording system would be 204.8 Hz (Figure 3.1.2.4d). This decision was based on the fact that this recording system is limited to record one screen therefore a compromise between time and precision was necessary. A second sampling rate was selected for the calibration procedure (51.2 Hz) due to the fact that during the calibration procedure we are interested in the sensitivity of our recordings (i.e. how large the voltage step is) more than the time range.

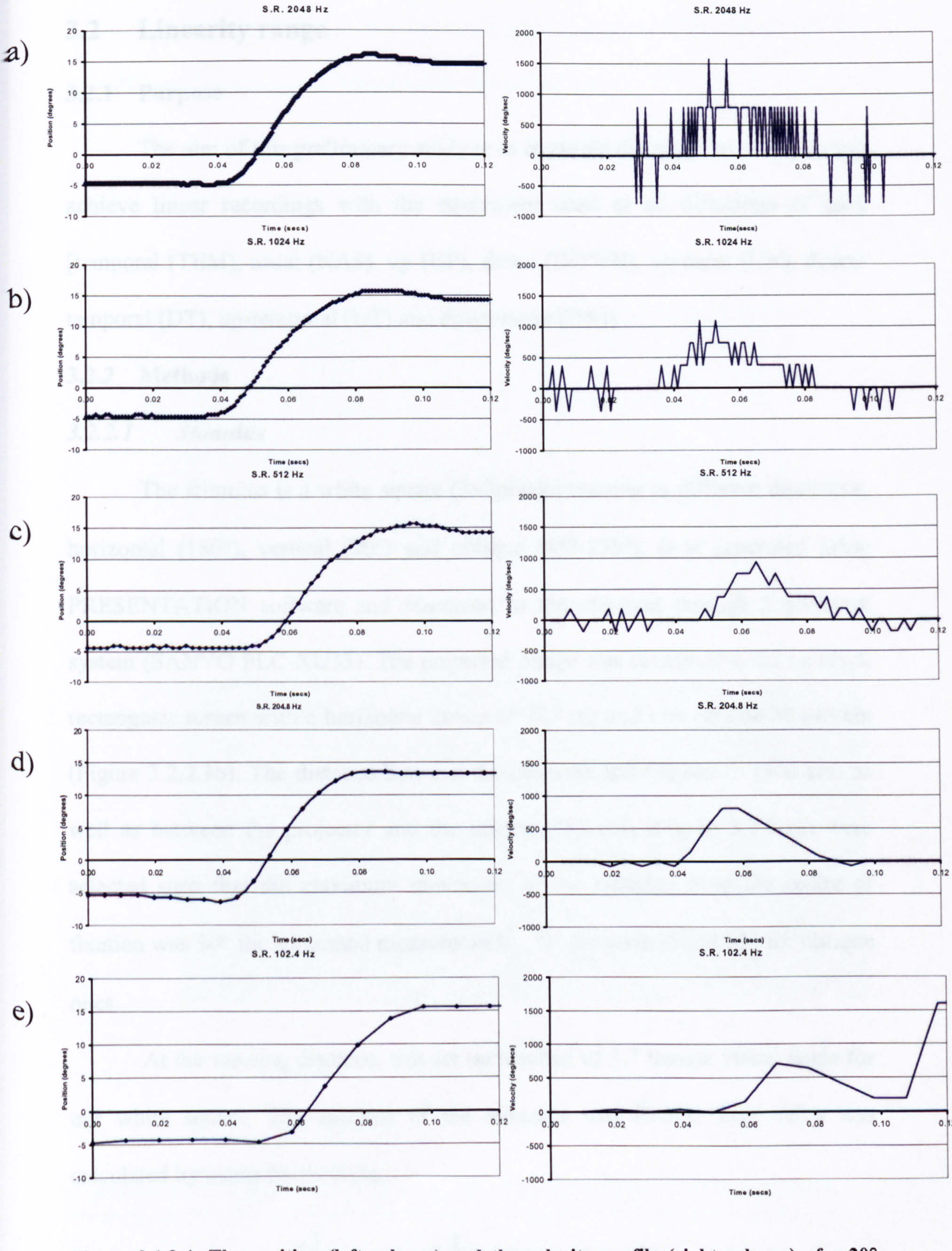


Figure 3.1.2.4: The position (left column) and the velocity profile (right column) of a 20° saccade in the horizontal direction (temporal) recorded under different time scales: (a) 2048 Hz (50 msec/div), (b) 1024 Hz (100 msec/div), (c) 512 Hz (200 msec/div), (d) 204.8 Hz (500 msec/div) and (e) 102.4 Hz (1000 msec/div). In position plots the data are not normalized thus there is a +5degree offset.

3.2 Linearity range

3.2.1 Purpose

The aim of this preliminary study is to establish the range where we could achieve linear recordings with the equipment used in all directions of gaze [temporal (TEM), nasal (NAS), up (UP), down (DOWN), up-nasal (UN), down-temporal (DT), up-temporal (UT) and down-nasal (DN)]

3.2.2 Methods

3.2.2.1 Stimulus

The stimulus is a white square (3×3pixels) moving in different directions, horizontal (180°), vertical (90°) and oblique (45°-135°). It is generated using PRESENTATION software and presented to the observer through a projector system (SANYO PLC-XU33). The projected image was contained within a black rectangular screen with a horizontal extent of 307 cm and vertical one of 143 cm (Figure 3.2.2.1b). The distance between the observer and the screen (300 cm) as well as between the projector and the screen (353 cm) (Figure 3.2.2.1a) were selected such that the maximum movement of the stimulus from the centre of fixation was 30° for horizontal measurements, 20° for vertical and 25° for oblique ones.

At the viewing distance, this set up resulted of 5.7 minarc visual angle for our white square. The contrast of the stimulus was 99.5%. This value was calculated by using the formula:

$$\%\ \text{contrast} = \left(\frac{L_{\text{stimulus}} - L_{\text{background}}}{L_{\text{stimulus}} + L_{\text{background}}}\right) \times 100$$

Our measured luminance values were $L_{stimulus} = 139.2\ cd/m^2$ for the stimulus and $L_{background} = 0.296\ cd/m^2$ for the background.

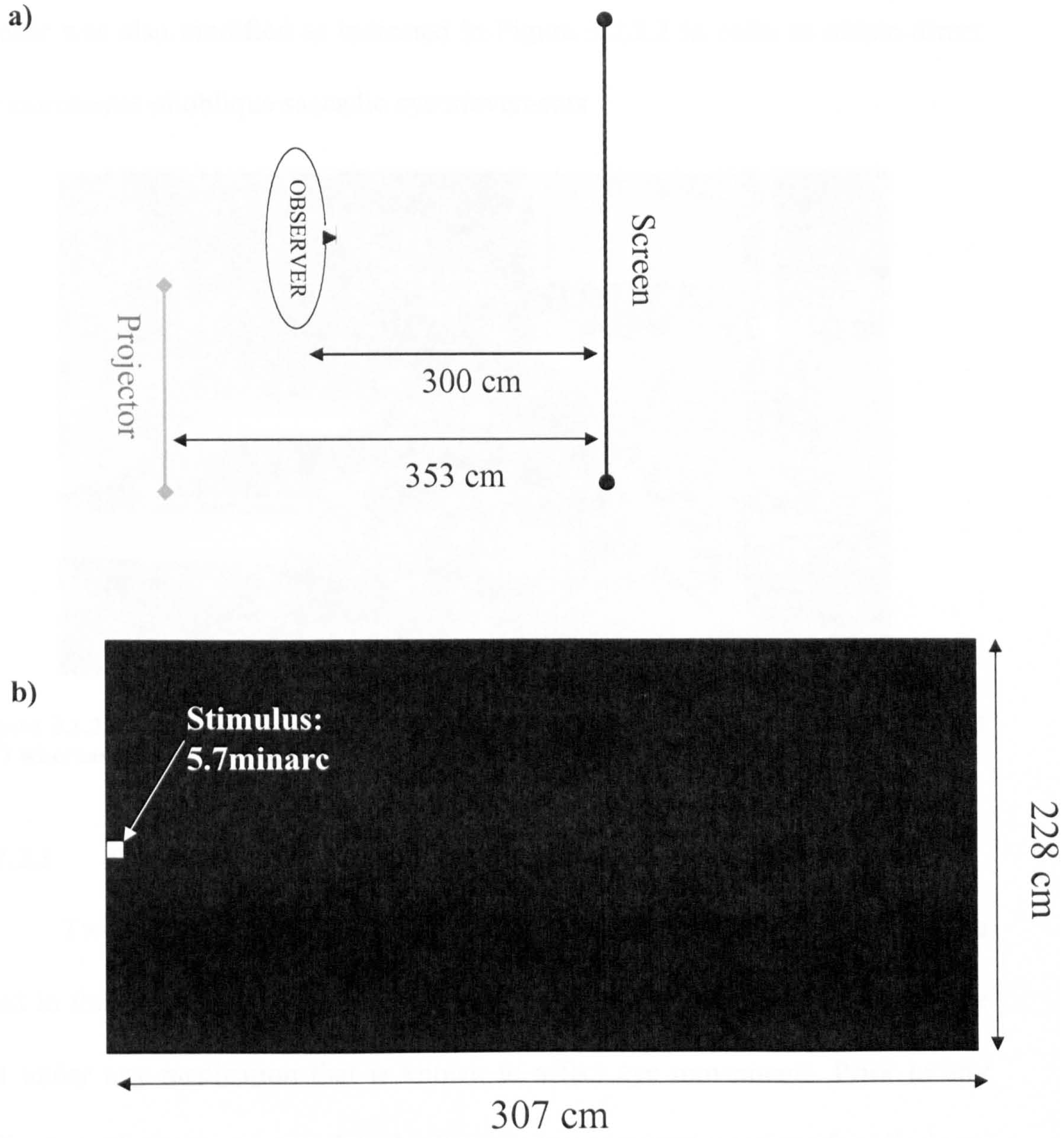


Figure 3.2.2.1: Schematic diagram of the set up system showing the distances between the observer and the screen (300 cm) and between the projector and the screen (353 cm).

3.2.2.2 Eye movement monitoring apparatus/ Recording system

The eye movements monitoring apparatus and recording system used in this study are the same as described previously in sections 3.1.2.2-3.1.2.3. The eye tracker was also modified as indicated in Figure 3.2.2.2 in order to obtain direct measurements of oblique saccadic eye movements

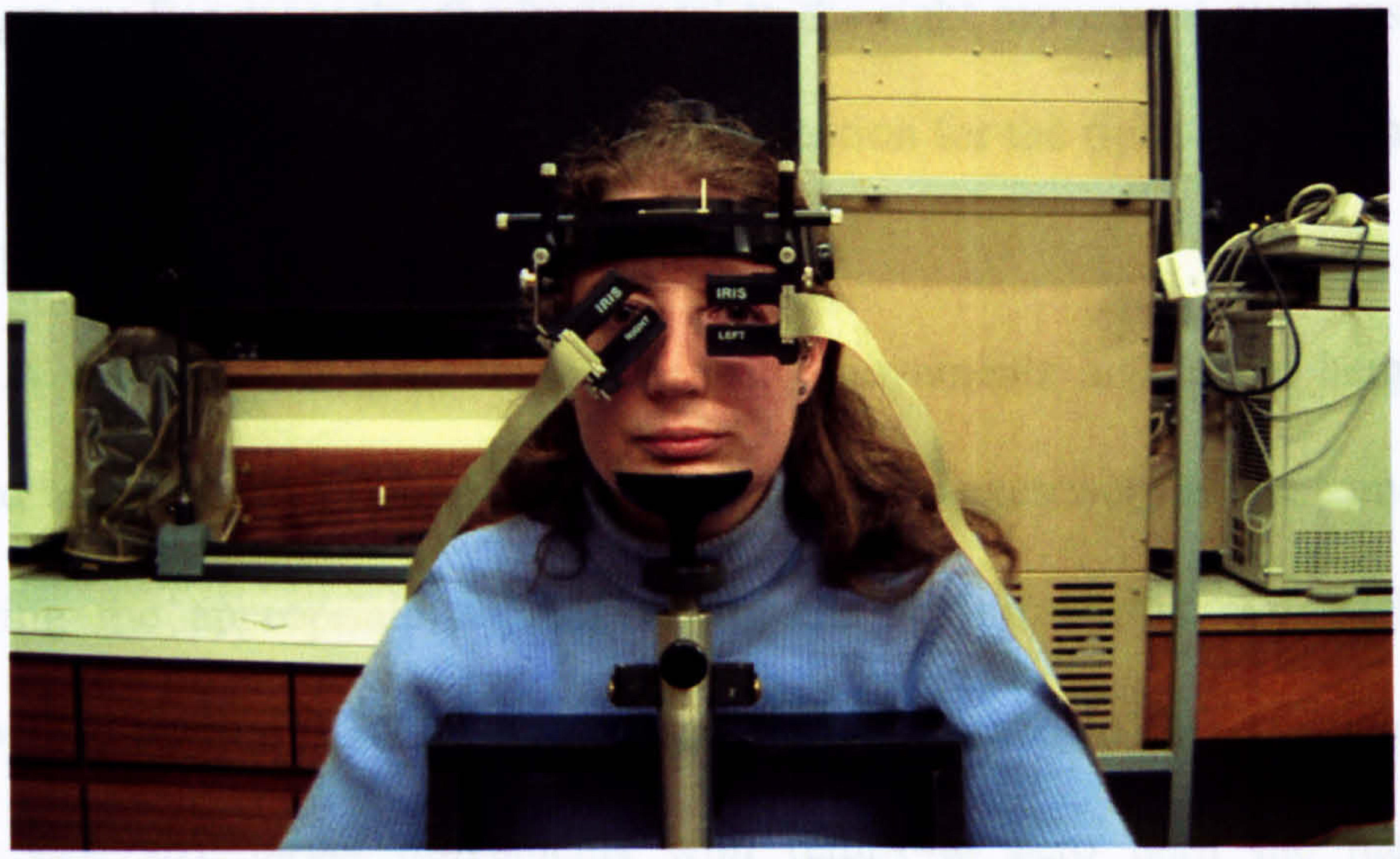


Figure 3.1.2.2: The right eye shows the sensor orientated for oblique recordings (UN and DT) whereas the left eye is set for horizontal directions (TEM and NAS).

3.2.2.3 Observers

Two visually normal observers [KP (27 years) and MB (33 years)] were used in this pilot study. Subjects in this study had no systemic disease and were not under any medication that is known to affect eye movements. Prior to any collection of eye movement data, both subjects underwent a series of preliminary optometric tests (LogMAR visual acuity, cover test, motility test and stereopsis) to establish that binocular vision was normal. Visual acuity in both observers was at least 0.0 LogMAR. An optical correction (full aperture trial case lenses) was only necessary for observer KP.

3.2.2.4 Experimental Procedure

Monocular recordings were carried out in a darkened room and observers fixed on the white square target at a viewing distance of 300 cm. The eye with better visual acuity or the dominant eye was selected in each individual. The action of the extraocular muscle was used to classify the directions under investigation. For example, the horizontal to the right movement, with respect to the subject, was identified as the temporal direction for the right eye and the nasal direction for the left eye respectively.

A chinrest was used to reduce head movements and target height was adjusted to ensure that the target and the observer's eyes were at the same level. Following the appropriate adjustments in the setting of the eye tracker (as described in section 3.1.2.2), both observers were asked to follow sequential 5 degree step size target movements with return to zero until the maximum amplitude range was attained in all eight different directions of gaze under investigation. Figure 3.2.2.4 shows these directions. This task was repeated 5 times in every direction for each observer respectively. Recordings of the observers' saccades were made at a sampling rate of 51.2 Hz.

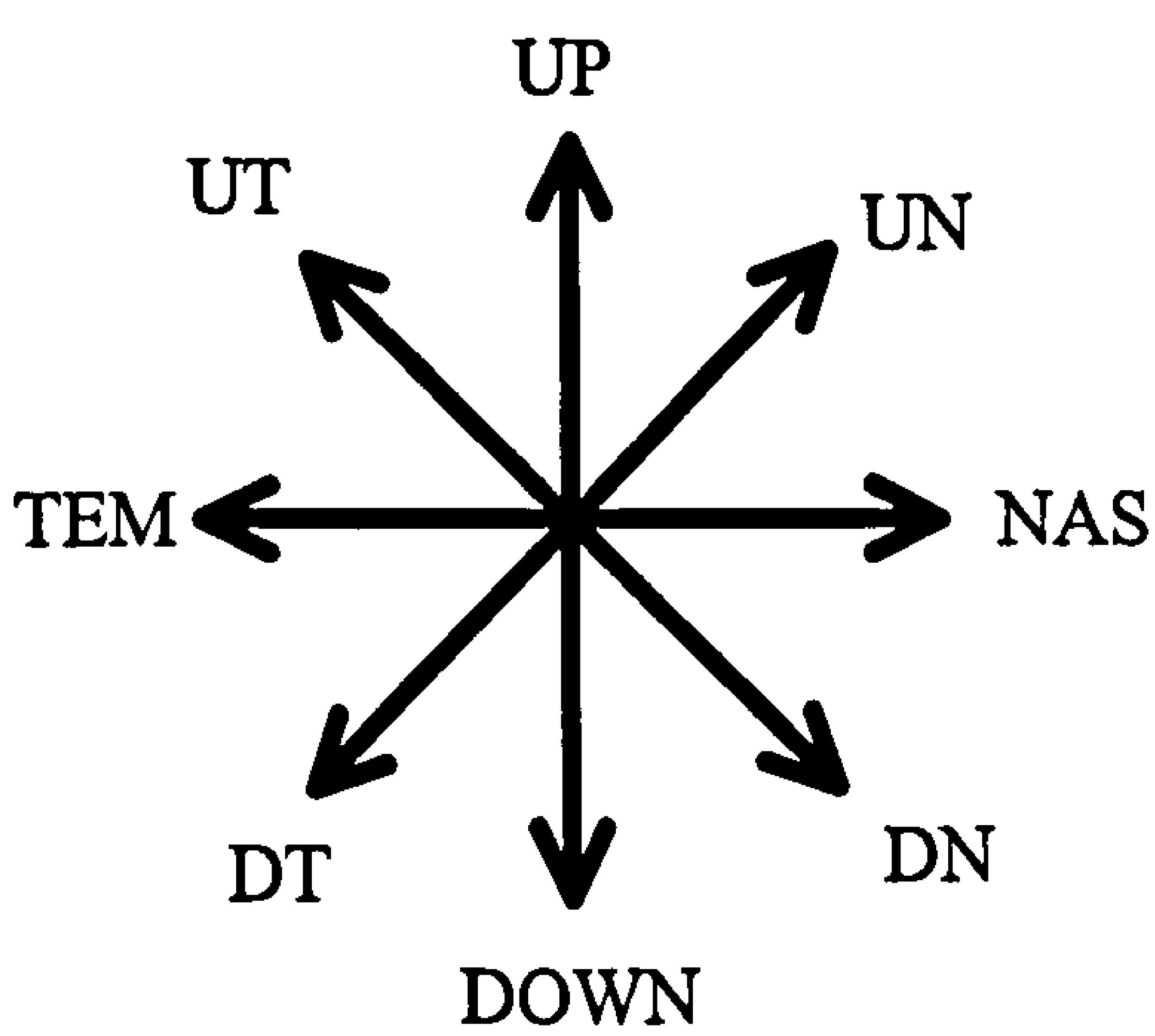


Figure 3.2.2.4:A schematic diagram that shows all the directions of gaze under investigation [temporal (TEM), nasal (NAS), up (UP), down (DOWN), up nasal (UN), down temporal (DT), up temporal (UT), down nasal (DN)].

3.2.2.5 Data Processing

Data were collected for the eye movement response (channel 1) and for the stimulus (channel 2). The movement of the eye appeared as a square step signal on the oscilloscope screen indicating the different voltage of each LED position. The output signal from these two channels were saved and transferred as ASCII files for data processing.

MATLAB was selected to process/ window the data due to its broad capabilities. At the start of each session, observers performed a calibration run with target steps of 5°, 10° and 15° (Figure 3.2.2.5.1a). The first script of MATLAB is consisted of several commands that loads a selected file and then separates the calibration data (1024 points) from those of the experiment. In that calibration data file, the program finds the steps and averages the plateau heights. A calibration curve is fitted through those average values, which were selected by the experimenter and corresponded to the responses of each observer. The slope and intercept of this curve were used to convert the corresponding experimental data to degrees (Figure 3.2.2.5.1b).

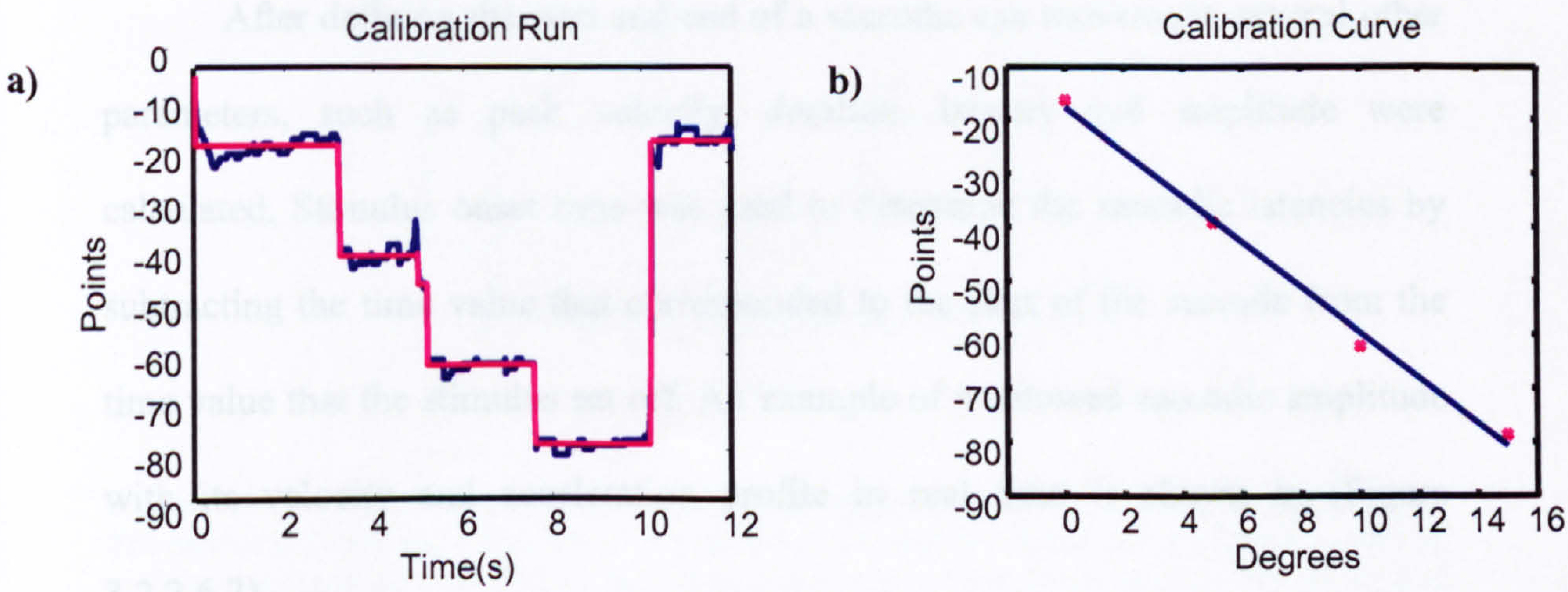


Figure 3.2.2.5.1: (a) Graph shows an example of the calibration response. Blue line represents the collected data whereas the pink line shows the average values of each step. (b) Graph shows an example of calibration curve where a best-fitted line was plotted through the average values of each step (pink markers).

Furthermore, another MATLAB script loads the experimental data and separates them into two columns, one for position (points) and the other for stimulus (points). Subsequently, those data are converted into degrees by using the slope and intercept values that were calculated previously from the calibration. The output of this processing is a graph that represents position as a function of time. Besides separating the data into smaller files, several scripts are used to determine the start and end of the saccade and calculate the saccadic parameters under investigation. The start and end of a saccade were defined on the basis of a minimum velocity and time. More specifically, when the eye speed exceeded a minimum velocity (e.g. 40 deg/sec) for longer than a minimum time (e.g. 30 msecs) then the beginning of saccade was identified and it ended when the velocity dropped back below that minimum velocity (Baloh, *et al.* 1975).These criteria (min velocity and min time) that were used to window the data were sometimes manually altered due to intrasubject variability. This occurred in 50 % of our observers and the maximum values of those criteria (minimum velocity and time) were 70 deg/sec and 50 msecs.

After defining the start and end of a saccadic eye movement, several other parameters, such as peak velocity, duration, latency and amplitude were calculated. Stimulus onset time was used to determine the saccadic latencies by subtracting the time value that corresponded to the start of the saccade from the time value that the stimulus set off. An example of windowed saccadic amplitude with its velocity and acceleration profile in real time is shown in (Figure 3.2.2.6.2).

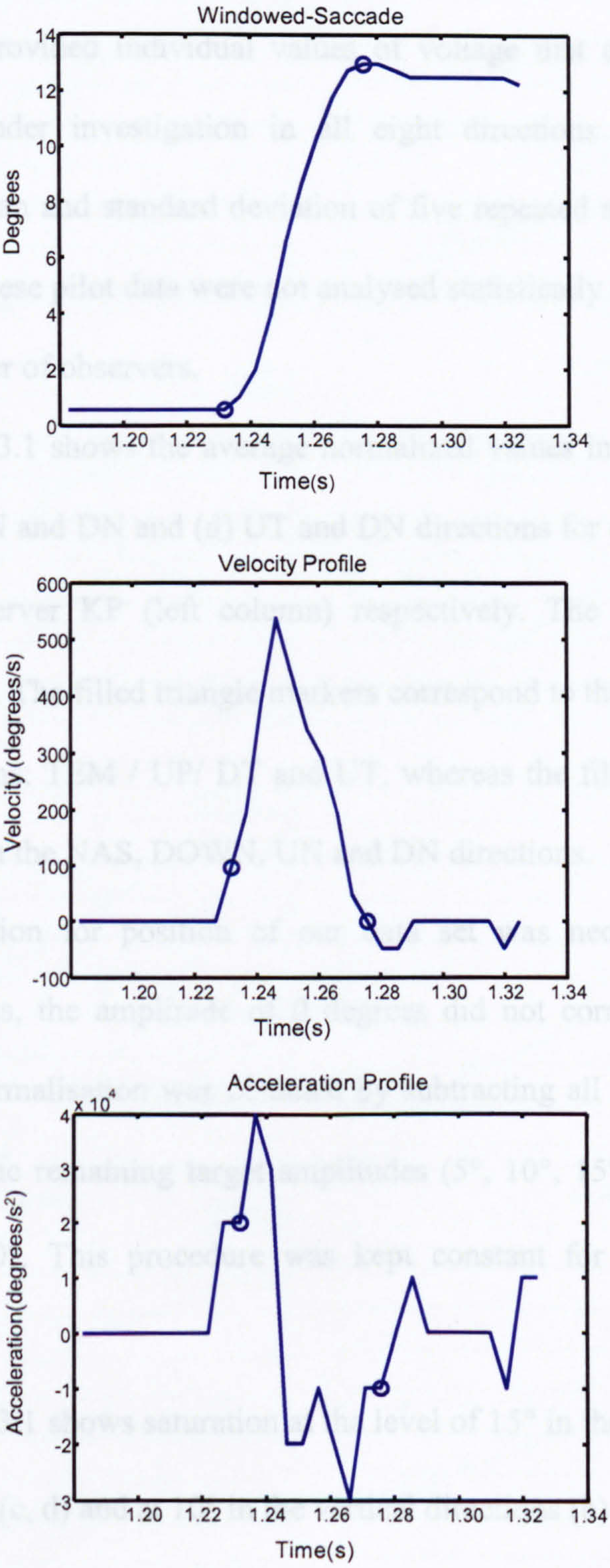


Figure 3.2.2.5.2: The top figure shows a typical saccadic response to a 10° horizontal step. The circles indicate start and end of the saccade. The middle figure shows velocity profile of the same saccade and the one on the bottom shows the acceleration profile. The horizontal axis shows the real time that the event occurred.

3.2.3 Results / Discussion

Analysis provided individual values of voltage that correspond to each amplitude size under investigation in all eight directions of gaze for both observers. The mean and standard deviation of five repeated measurements were also calculated. These pilot data were not analysed statistically across subjects due to the small number of observers.

Figure 3.2.3.1 shows the average normalized values in (a) the horizontal, (b) vertical, (c) UN and DN and (d) UT and DN directions for observer MB (right column) and observer KP (left column) respectively. The error bars are ±1 standard deviation. The filled triangle markers correspond to the data values of the following directions: TEM / UP/ DT and UT, whereas the filled square markers show the data from the NAS, DOWN, UN and DN directions.

Normalization for position of our data set was necessary due to the windowing process, the amplitude of 0 degrees did not correspond to 0 volts. Therefore, this normalisation was obtained by subtracting all voltage values that corresponded to the remaining target amplitudes (5°, 10°, 15° etc) with the one corresponded to 0°. This procedure was kept constant for all directions and observers.

Figure 3.2.3.1 shows saturation at the level of 15° in the horizontal (a) and oblique directions (c, d) and at 10° in the vertical directions (b).

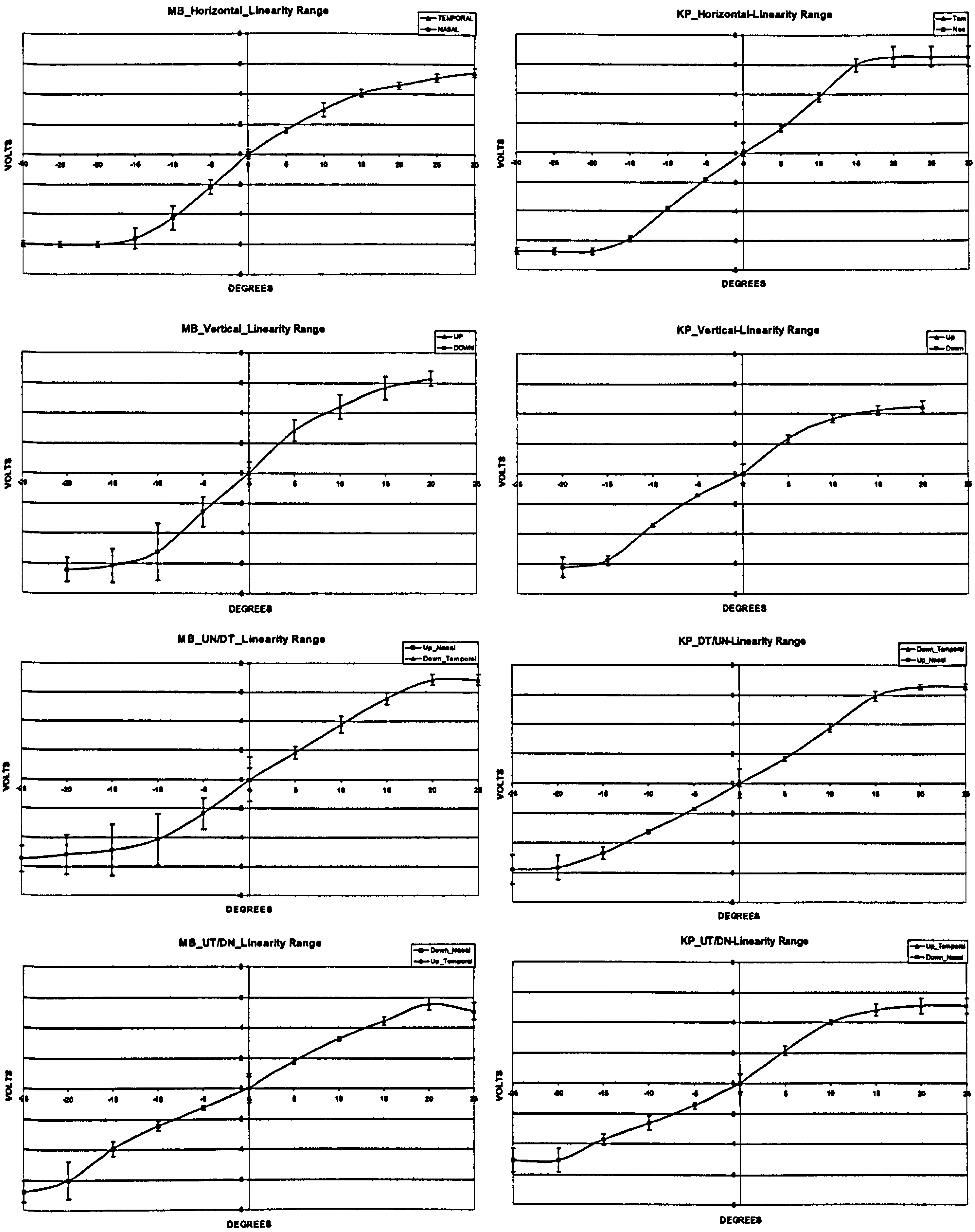


Figure 3.2.3.1 Linearity range graphs showing the average normalized values in (a) the horizontal, (b) vertical, (c) UN and DN and (d) UT and DN directions for observer MB (right column) and observer KP (left column) respectively. The error bars are ±1 standard deviation. The filled triangle markers correspond to the data values of the following directions: TEM / UP/ DT and UT. Whereas the filled square markers show the data from the NAS, DOWN, UN and DN directions.

A linear regression analysis was applied through the data set of each observer and direction. Figure 3.2.3.2 shows the best-fit line (y) up to 15° for the horizontal and oblique directions and up to 10° for the vertical ones, therefore the relationship between the variables of the x-axis (target amplitude) and y-axis (eye position expressed in volts). The R-squared values show how good this line fits to the data.

The results of this set of data indicated that the system is linear up to 10° for vertical saccadic eye movements and up to 15° for horizontal and the four oblique directions. Hence we decided to proceed with a size of 10° saccadic eye movements. This decision was also related to the report made by Becker and Jurgens in 1991. In that study they showed the trajectories of horizontal, vertical and 45° oblique saccades from the centre to an eccentric position of ± 20° in all meridians. Their data show that in 10° the curvature and the scatter remain relatively small in comparison to the 20°.

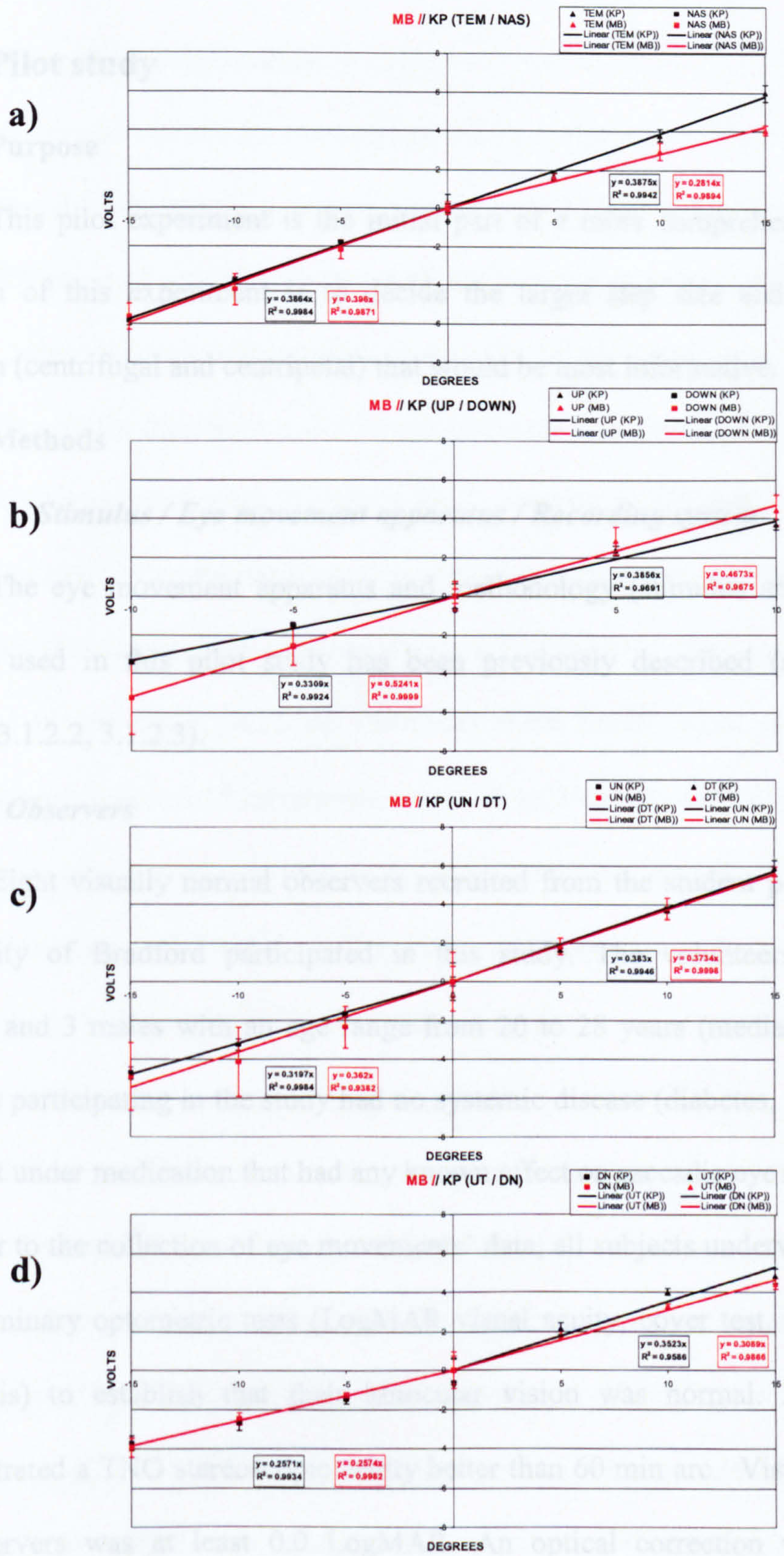


Figure 3.2.3.2: Linear relationship between the eye position expressed in volts (y-axis) and the target position (x-axis). The triangle markers that are presented on the top right side of each individual graph correspond to directions such as TEM, UP, DT and UT. KP's data are shown with the black markers and lines whereas the red markers and lines indicate MB's data. The error bars indicate ±1 STDEV.

3.3 Pilot study

3.3.1 Purpose

This pilot experiment is the initial part of a more comprehensive study. The aim of this experiment is to decide the target step size and the orbital direction (centrifugal and centripetal) that would be most informative.

3.3.2 Methods

3.3.2.1 Stimulus / Eye movement apparatus / Recording system

The eye movement apparatus and methodology (stimulus and recording system) used in this pilot study has been previously described (see sections 3.1.2.1, 3.1.2.2, 3.1.2.3).

3.3.2.2 Observers

Eight visually normal observers recruited from the student population of University of Bradford participated in this study. The volunteers were five females and 3 males with an age range from 20 to 28 years (median 24 years). Subjects participating in the study had no systemic disease (diabetes, thyroid) and were not under medication that had any known effect on saccadic eye movements.

Prior to the collection of eye movements' data, all subjects underwent a series of preliminary optometric tests (LogMAR visual acuity, cover test, motility and stereopsis) to establish that their binocular vision was normal. All subjects demonstrated a TNO stereoscopic acuity better than 60 min arc. Visual acuity in all observers was at least 0.0 LogMAR. An optical correction was used if necessary in the form of the subjects' own contact lenses or full aperture trial case lenses.

3.3.2.3 Experimental procedure

Monocular recordings were carried out in a darkened room and observers fixated on red LED target at a viewing distance of 114 cm (see section 3.1.2.1 for a full description of set up). The eye with the best visual acuity or the dominant eye was selected in each individual. The action of the extraocular muscle was used to classify the directions under investigation (as described in section 3.2.2.5).

A chinrest was used to reduce head movements and target height was adjusted to ensure that the target and the observer's eyes were at the same level. Following the appropriate adjustments in the setting of the eye tracker (as described in section 3.1.2.2), all observers were firstly asked to perform a calibration sequence of 5° incremental steps (0°→ 5°→ 10°→15°) for horizontal and oblique eye movements (Figure 3.3.2.5.1). For the vertical directions (up-down) observers performed a similar calibration sequence with 5° incremental steps up to 10° (0°→ 5°→ 10°). This calibration process was carried out prior to the measurement of the corresponding direction.

During the experimental sessions, the observer was asked to fixate on the centre of the target bar and perform a 5-degree and 10-degree step size centrifugal (from primary position to an eccentric one) saccades or centripetal (from an eccentric position to the primary one) saccades in all eight directions under investigation (Figure 3.2.2.5). Calibration sequences were recorded at a sampling rate of 51.2 Hz whereas the experimental sequences were measured at a sampling rate of 205 Hz. Each trial consisted of six saccades. Between these trials, subjects had short breaks in order to avoid the effect of fatigue and to allow the sensors and stimulus to be reset for the next trial. The order of presentation was randomised between and within the trials of each observer in order to avoid possible effects of fatigue.

3.3.2.4 Data processing

The processing of the data in this pilot study is the same as the one described in section 3.2.2.6.

3.3.3 Results / Discussion

For each observer, individual recordings were obtained for each saccadic parameter (latency, peak velocity, amplitude and duration) in eight directions of gaze. No statistical analysis across subjects and directions was carried out due to the small number of observers.

Figure 3.3.3.1 shows the average values of all observers when all directions were combined in each saccadic parameter for 5° and 10° centrifugal saccadic eye movements. The inner red line with the circular markers corresponds to the 5° data where the outer blue line with the square markers corresponds to the 10° data. Errors bars are not included in this Figure due to the fact that they are smaller than the markers used. A visual inspection of Figure 3.3.3.1 revealed that the target step of 5° did not provide with more information than the 10°. Similarly the other remaining sets of data were examined [centripetal (5°→ 0° and 10°→ 0°)] and the same conclusion was drawn. The main interest in this set of data was to decide which (if both) step sizes and orbital direction would provide different information.

A review of the literature has revealed that oblique saccadic movements are most often calculated in terms of their horizontal and vertical components, in other words they are indirectly inferred based on vertical and horizontal recordings (Yarbus, 1967;Bahill and Stark, 1975,1977; Viviani, *et al.* 1977; Van Gisbergen, *et al.* 1985; King, *et al.* 1986; Deubel, 1987; Grossman and Robinson, 1988; Smit and Van Gisbergen, 1990; Becker and Jurgens, 1990; Leigh and Zee, 1999). In this pilot study, due to our eye tracker modification, we were able to obtain direct measurements of saccadic parameters in oblique directions, which were similar (average latency of 200 msecs, peak velocity range within 350-700 deg/sec and duration less than 100 msecs) to those obtained from indirect measurements (Becker, 1991; Ciuffreda and Tannen, 1995).

A comparison between the saccadic metrics in the centrifugal (Figure 3.3.3.1) and centripetal (Figure 3.3.3.2) directions revealed that there are no differences in their values. In contrast, to this set of data, Becker (1991) reported that centrifugal 30 degrees saccadic eye movements have slower peak velocities and longer duration when compared to centripetal saccadic eye movements. This discrepancy between the two studies might suggest that there is an effect of orbital direction (centrifugal versus centripetal) in larger eccentricities but further investigation with a larger number of observers is necessary to resolve this matter.

From the results of this data set, we showed that veridical measurements of oblique eye movements using the modified eye tracker are obtainable. We also decided that 5° step size saccades did not reveal any additional information than those in 10°.Thus we decided to use 10° step size for our comprehensive study. Another reason why we decided to use this latter step size is based on previous study. In 1991, Becker suggested that the curvature of the trajectories of oblique saccades is increased and scattered compared to those of purely horizontal or vertical saccades. Their results show that the trajectories' curvature is relatively linear for 10-degree steps. In addition, Cuiffreda and Tannen (1995) reported that the most naturally occurring saccades are less than 15 degrees of amplitude

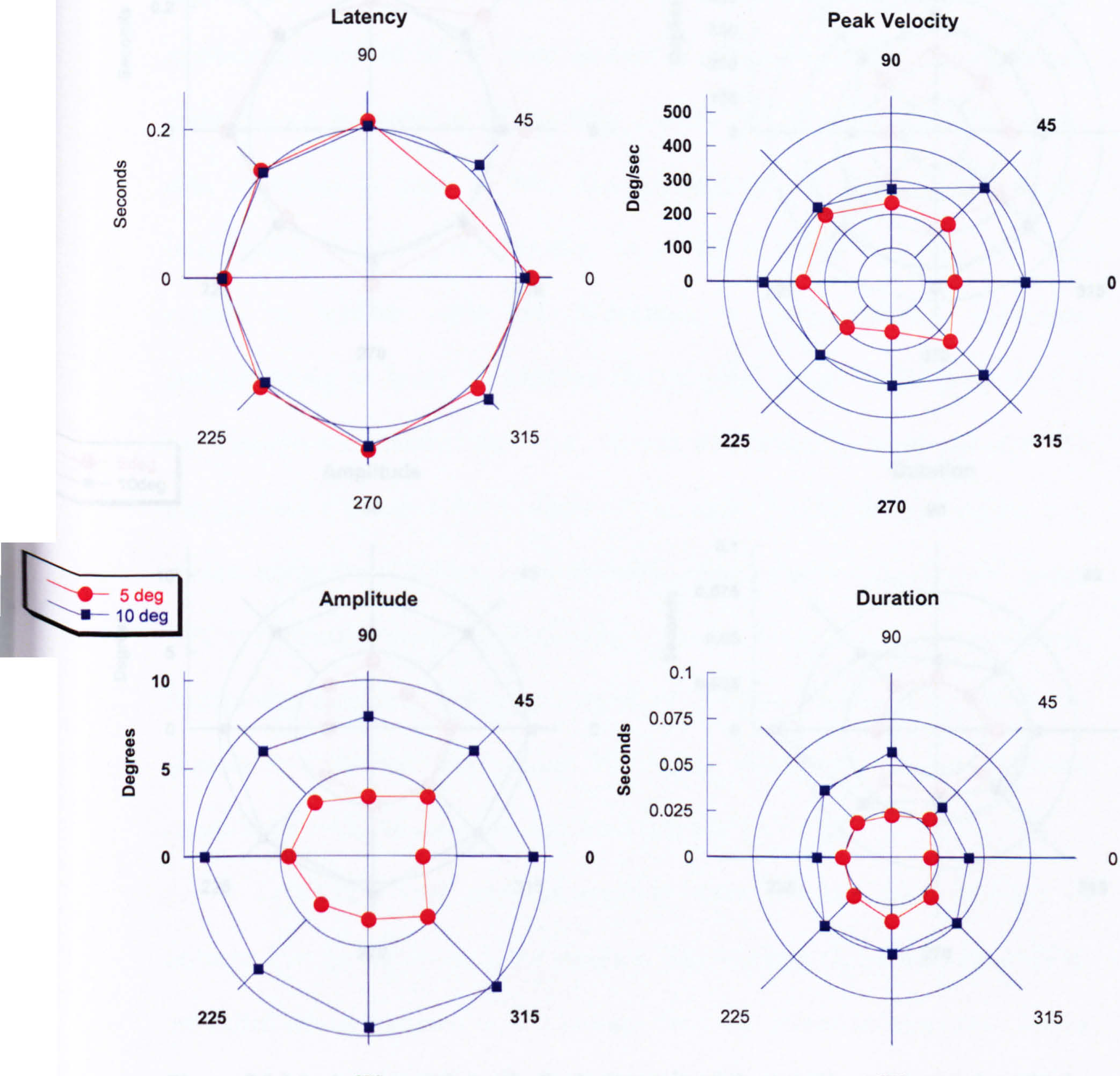


Figure 3.3.3.1. Average values of all observers in each saccadic parameter (amplitude, latency, duration and peak velocity) for 5° and 10° centrifugal (from the centre of fixation to an eccentric position) saccadic eye movements (SET I). The inner red line with the circular markers corresponds to the 5° data where the outer blue line with the square markers corresponds to the 10° data. Errors bars are not included for clarity reasons.

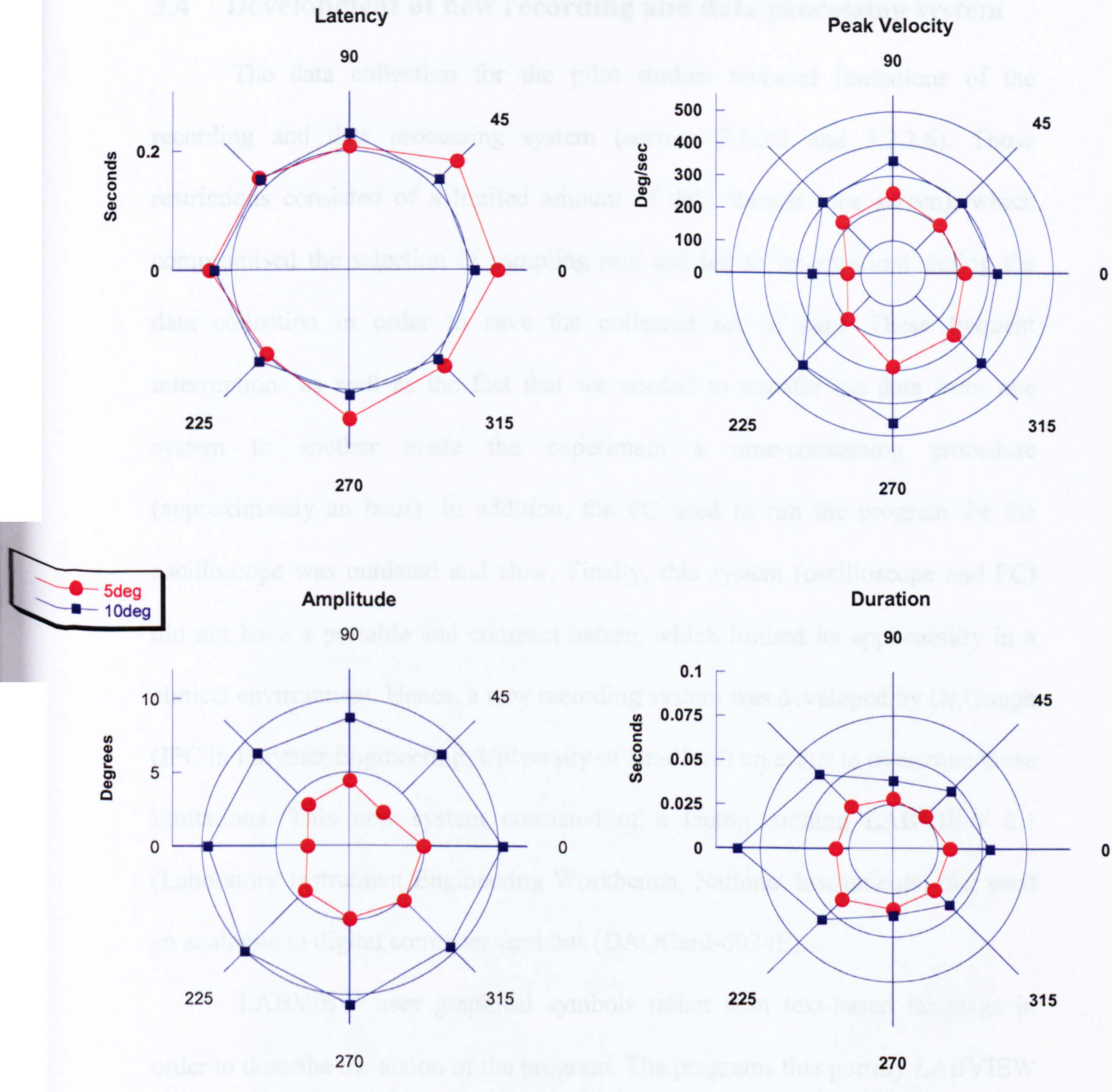


Figure 3.3.3.2. Average values of all observers in each saccadic parameter (amplitude, latency, duration and peak velocity) for 5° and 10° centripetal (from an eccentric position to the centre of fixation) saccadic eye movements (SET I). The inner red line with the circular markers corresponds to the 5° data where the outer blue line with the square markers corresponds to the 10° data. Errors bars are not included for clarity reasons.

3.4 Development of new recording and data processing system

The data collection for the pilot studies revealed limitations of the recording and data processing system (section 3.1.2.3 and 3.2.2.6). Those restrictions consisted of a limited amount of data storage (one screen), which compromised the selection of sampling rate and led to interruptions during the data collection in order to save the collected set of data. These frequent interruptions as well as the fact that we needed to transfer the data from one system to another made the experiment a time-consuming procedure (approximately an hour). In addition, the PC used to run the program for the oscilloscope was outdated and slow. Finally, this system (oscilloscope and PC) did not have a portable and compact nature, which limited its applicability in a clinical environment. Hence, a new recording system was developed by Dr Gough (IPC in Polymer Engineering, University of Bradford) on effort to overcome those limitations. This new system consisted of a laptop running LABVIEW 6.1 (Laboratory Instrument Engineering Workbench, National Instruments) that used an analogue to digital converter card bus (DAQCard-6024E).

LABVIEW uses graphical symbols rather than text-based language in order to describe the action of the program. The programs that portray LABVIEW are called virtual instruments (VI) because their appearance and operation imitate physical instruments like oscilloscopes (LABVIEW Help manual).

In our system there are two separate VI, for the calibration and experimental recordings separately. Figure 3.4.1 shows the front panel for the calibration sequence and contains the following elements:

1. A digital oscilloscope that records two traces one for the stimulus and one for the eye position.
2. A start/end button.
3. Four different terminals that must be set up prior to any recording:
    i) The file terminal that sets the path stem and file header.
    ii) The terminal describing the direction of eye movement we are recording.
    iii) The sampling rate terminal
    iv) The projection terminal (screen width and distance to the screen)

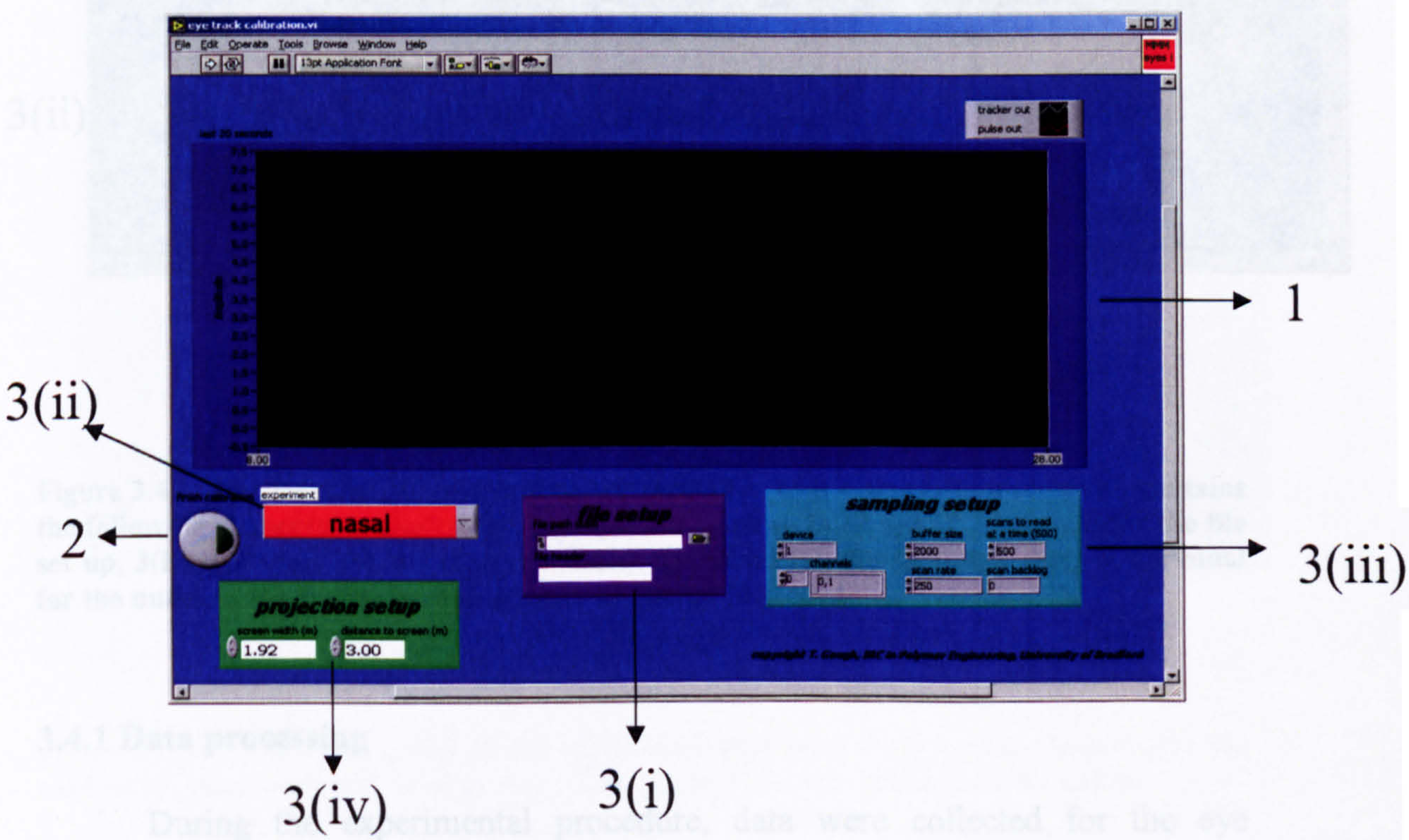


Figure 3.4.1: The front panel used during the recording of the calibration sequence contains the following elements: 1. Digital oscilloscope, 2. Start/end button , 3(i). Terminal for the file set up, 3(ii). Terminal for the direction, 3(iii). Terminal for the sampling rate, 3(iv). Terminal for the projection set up.

Figure 3.4.2 shows the front panel for the experimental sequence. This front panel contains all the elements of the calibration front panel except the terminal that shows the projection set up (3iv) in Figure 3.4.1. Instead, it has a terminal where the number of repeated measurements is indicated (4).

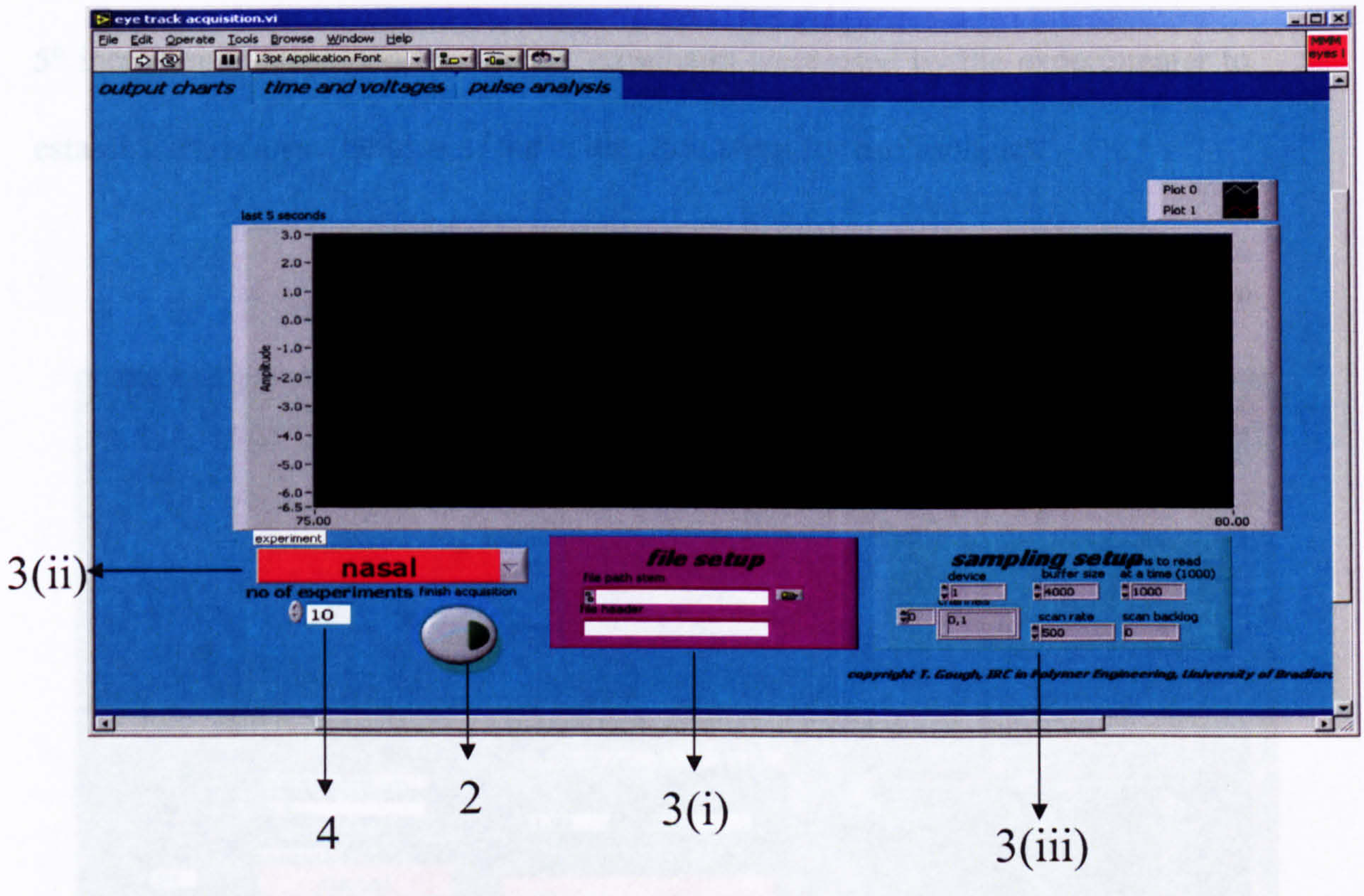


Figure 3.4.2: The front panel used during the recording of the acquisition sequence contains the following elements: 1. Digital oscilloscope, 2. Start/end button, 3 (i). Terminal for the file set up, 3(ii). Terminal for the direction, 3(iii). Terminal for the sampling rate, 4. Terminal for the number of repeated measurements we intend to record.

3.4.1 Data processing

During the experimental procedure, data were collected for the eye position response (channel 1/white trace), which appeared as a square step signal on LABVIEW's front panel indicating the different voltage of each target position and for the stimulus (channel 2/red trace) (Figure 3.4.1.1). The primary data analysis was made by the LABVIEW post-processing system where the saccadic metrics (latency, peak velocity, amplitude and duration) for each individual measurement were obtained. This post-processing system consisted of two programs, one for the calibration and the other for the experimental task.

The calibration post-processing program (Figure 3.4.1.1) loads the data file obtained previously during the calibration task where the observer performed 5° incremental steps. On the screen, crosshairs were used by the experimenter to establish the plateau heights of the calibration steps for each subject.

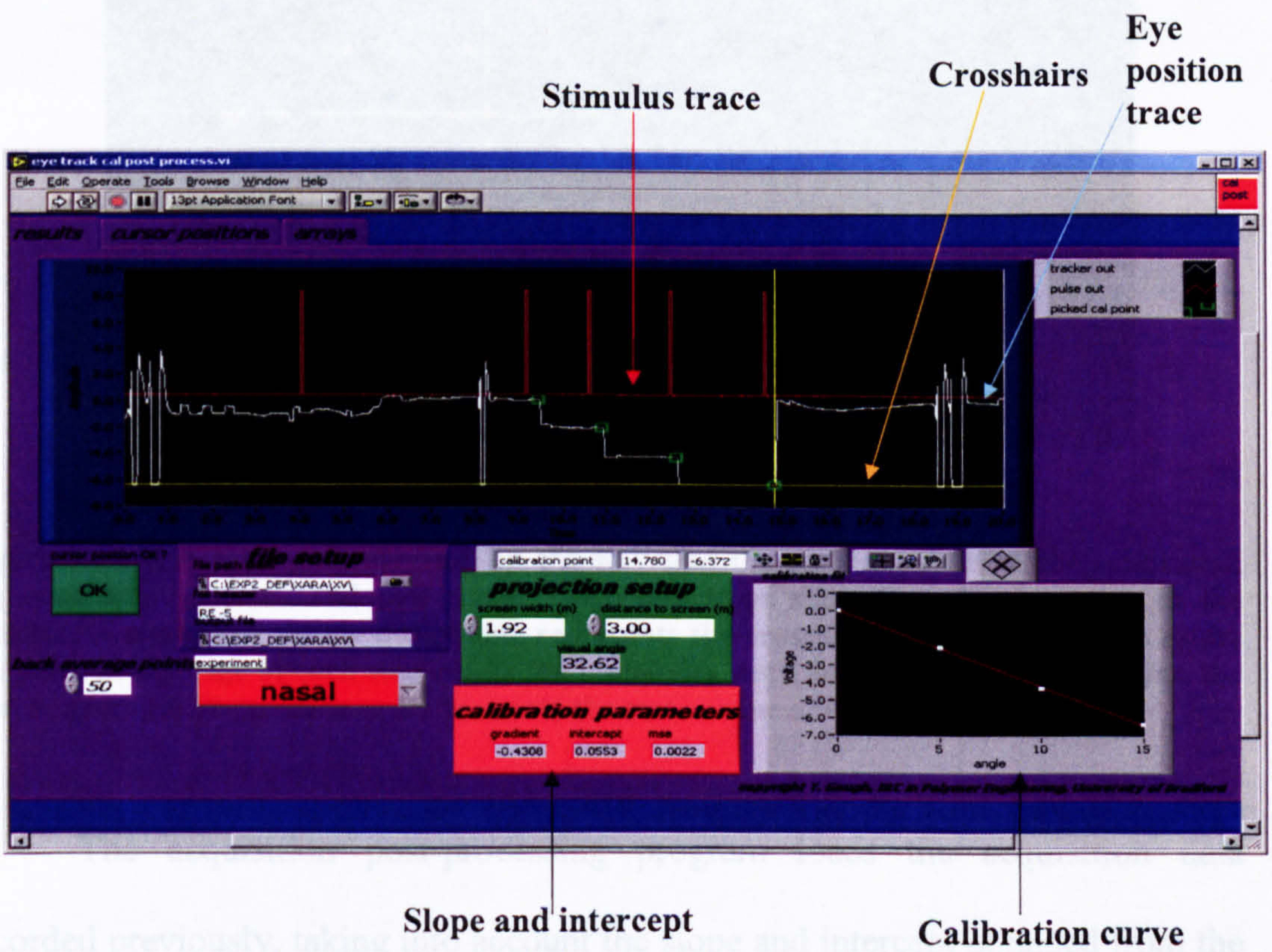


Figure 3.4.1.1: The front panel of the calibration post processing system. This shows the calibration sequence performed by one of our young observers in the nasal direction.

Figure 3.4.1.2 shows a schematic diagram on the way that those plateau values were selected and calculated. The white steps show the stimulus trace of the calibration steps. The yellow dotted line represent the crosshairs, which were positioned at the edge of each step in order to select by eye a point (green square).

Then the system averages 50 points (backwards) from that point in order to create the mean value of each plateau height.

A calibration curve is fitted through those average values corresponding to the responses of each observer. A curve was fitted for each orientation separately. The slope and intercept of this curve were also calculated and used to convert the corresponding experimental data to degrees (Figure 3.4.1.1).

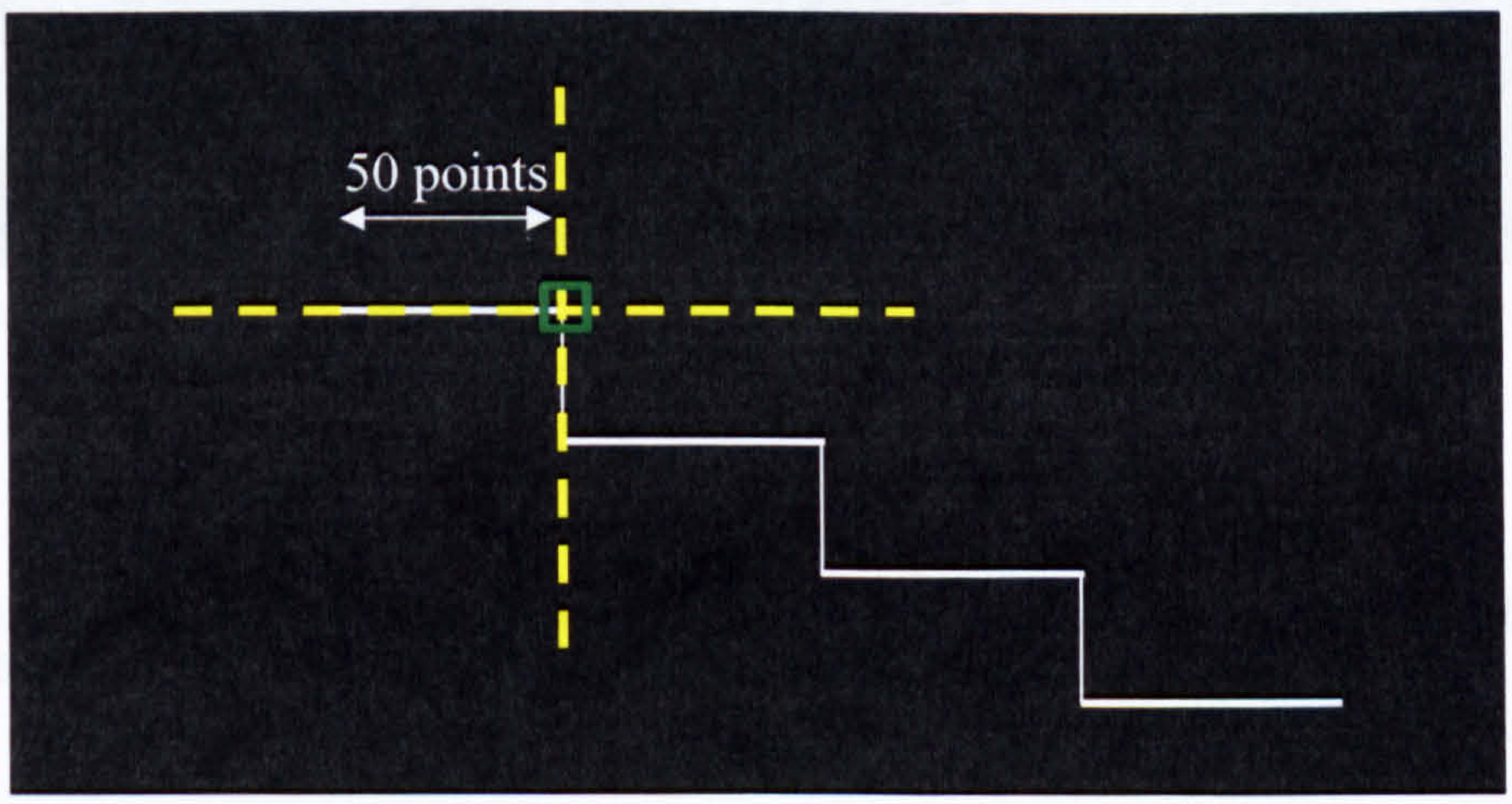


Figure 3.4.1.2: A schematic diagram on the way that the plateau values of the calibration sequence were selected and calculated. The white steps show the stimulus trace of the calibration steps. The yellow dotted line represents the crosshairs. The green square shows the point at the edge of each step where the crosshairs were positioned. From this point, the system averages 50 points in order to create the mean value of each plateau.

The acquisition post-processing program loads the acquisition data recorded previously, taking into account the slope and intercept obtained from the calibration post-processing analysis (Figure 3.4.1.3).

The start and end of a saccade was chosen by the experimenter and marked using the crosshairs. Figure 3.4.1.4 illustrates a magnified example of the first saccadic eye movement of the data shown in Figure 3.4.1.3. The yellow cursor was used to identify the start of the saccade whereas the blue one was used for the end of the saccade.

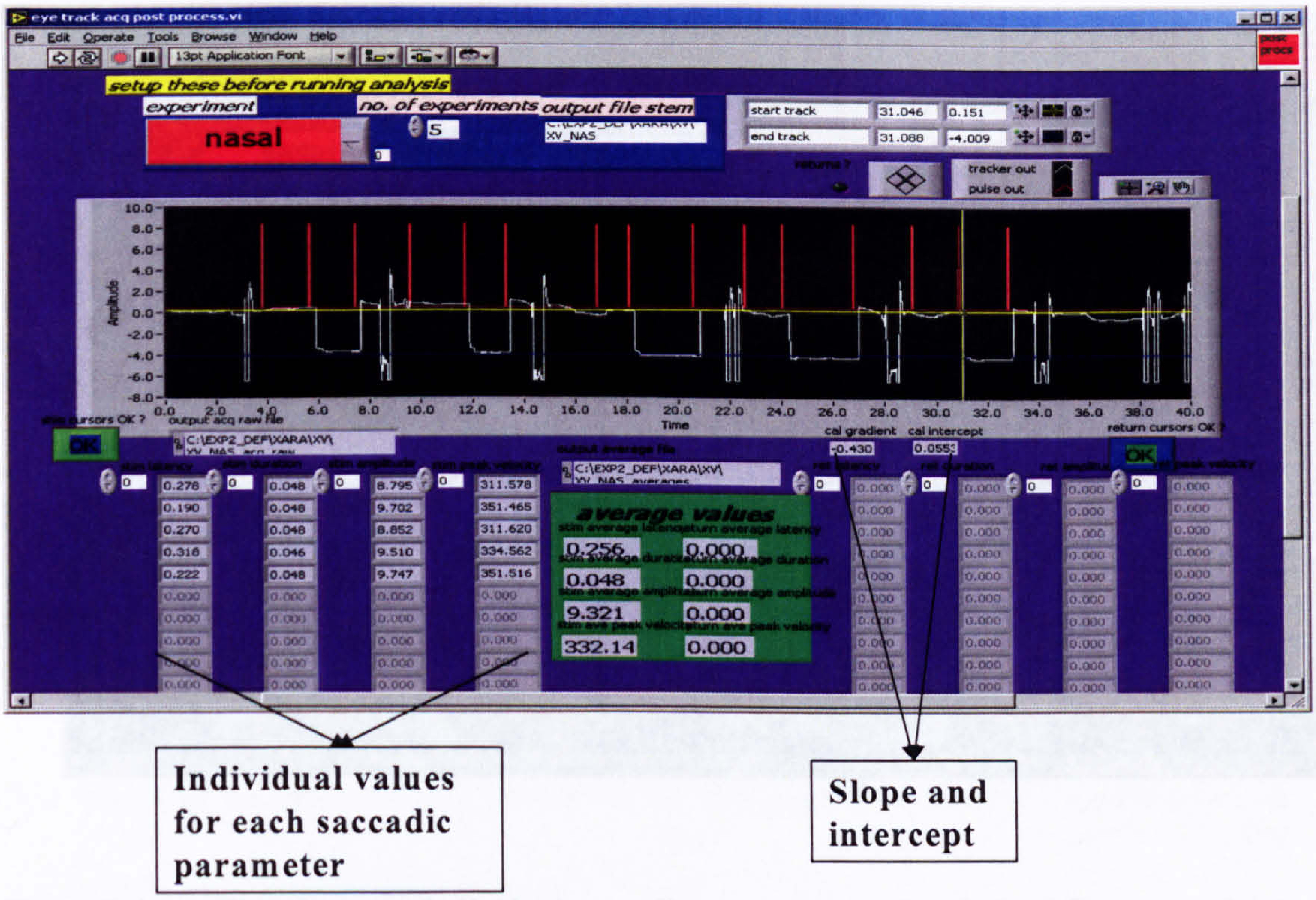


Figure 3.4.1.3: The front panel of the acquisition post processing system. This shows the data collected from one of our young observers in the nasal direction.

In order to verify this initial selection of the start and end of the saccade, the slope of the velocity profile was superimposed on the position profile (Figure 3.4.1.5). This verification was based on examining whether the intersection of the crosshairs on the position profile was overlapped with that of the velocity profile (i.e. with the start of the velocity curve). In all the cases the variation between the first selection (from the position profile) and the second one (from the velocity profile) was either negligible or non-existent. After defining the start and end of a saccade, latency, peak velocity, duration, and amplitude were also calculated. Stimulus onset time was used to determine the saccadic latencies by subtracting the time value that corresponded to the start of the saccade from the time value at which the stimulus moved (Figure 3.4.1.3).

Figure 3.4.1.4: This shows an individual saccadic eye movement performed from one of our young observers in the nasal direction. The yellow cursor shows the onset of the saccade marked by the examiner and the blue cursor shows the offset of the saccade.

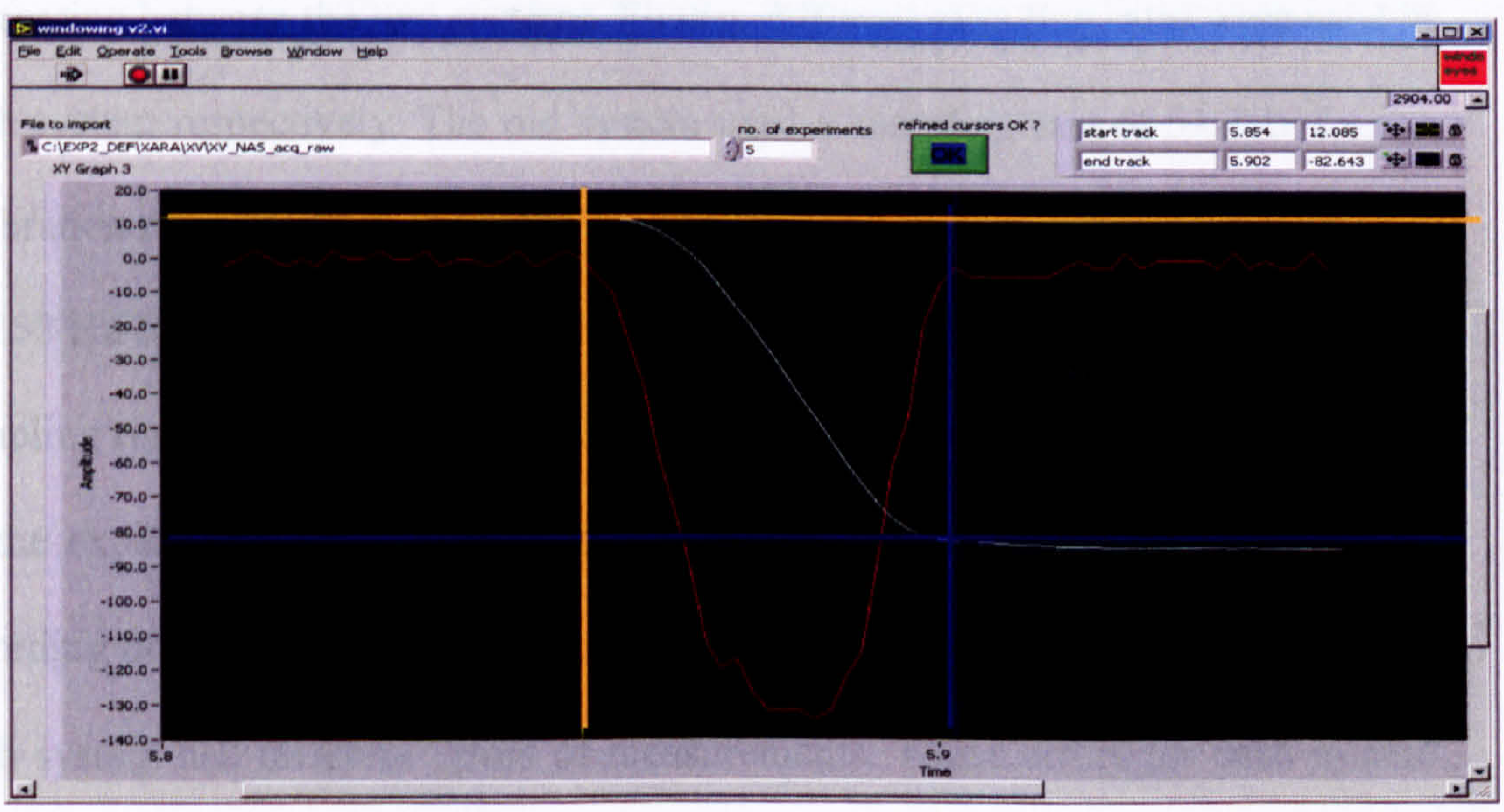


Figure 3.4.1.5: The white trace shows the position profile of a saccade of a young observer; the red trace shows the velocity profile of this saccade. This second trace helps the examiner to verify and correct if necessary the initial decision making on the onset and offset of the saccade.

3.5 Comparison of data recording and processing systems (MATLAB versus LABVIEW)

The first recording system consisted of Gould1604 digital storage oscilloscope and a PC. The analogue voltage signals that were collected from the eye tracker were transferred via an IEEE488 interface bus to that PC for analysis (see section 3.1.2.3). The second recording system as described in the previous section, consisted of a laptop running LABVIEW 6.1.

There is a similarity between the two systems. LABVIEW has an interface that works as an oscilloscope. Therefore the movement of the eye was detected as a squared step signal in both systems.

There are several differences between the collection as well as the data processing between the two systems. Firstly, different sampling rates were used in each system respectively. The old system used a sampling rate of 51.2Hz for the calibration run and 204.8Hz for the acquisition whereas the new system used a SR of 250 Hz for the calibration run and 500 Hz for the acquisition. A change in the sampling rates was based on the fact that with this system a continuous recording of the experiment could be carried out, overcoming the previous limitation on recording one screen at a single occasion. Due to this difference in sampling rates each system had different errors of measurements. Those errors for each system were calculated and are summarised in the Table 3.5.1.

These latency and duration errors were estimated as the smallest time interval (taking into consideration the sampling rate) that the system receives information from the eye tracker. In addition, the error for amplitude was estimated as the minimum signal in degrees that the recording receives from the eye tracker.

Table 3.5.1: Summarizes the error of measurement for each system respectively.

	OSCILLOSCOPE/MATLAB	*LABVIEW*
Latency	5 msecs	2 msecs
Duration	5 msecs	2 msecs
Peak Velocity	125 deg/sec	50 deg/sec
Amplitude	0.03 degrees	0.02 degrees

Another difference between the two systems was the way that the start- and end of a saccade is defined. In the old system this definition was made by a MATLAB script, which used two parameters, a minimum velocity and a minimum time. Thus the start of a saccade was identified when the eye velocity exceeded a specific value (i.e. 40deg/sec) for longer than a certain time (i.e. 30 msecs) and the end was identified when that eye velocity dropped back below that minimum value. In the new system, two cursors placed by the experimenter in the appropriate position delineated the start and end of the saccade, respectively. Sharpe and Zackon (1987) have previously used the same procedure to delineate the onset and offset of a saccade.

The former way of identifying the start and end of a saccade (with MATLAB) is automatic and could be considered as more accurate since it avoids the examiners bias. In contrast, data analysis with that system revealed that it is not as accurate as it seemed since we had to manually alter the defining criteria in approximately 50% of the cases. This procedure was also time-consuming. Therefore, we decided that the new method of defining the start and end provided with a good compromise by giving a representative onset of a saccade that is achieved in a reasonable time.

Data of one young observer (DC) performing 10 degrees saccades in all eight directions of gaze were recorded simultaneously with the two systems in order to compare if they would give similar results. Figure 3.5.1.1 shows superimposed eye position profiles of 10 degrees saccadic eye movements with the oscilloscope (black lines) and the LABVIEW (red lines). A visual inspection of Figure 3.5.1.1 indicates that similar eye position profiles are obtained with both recording systems. The data processing of the old system was made with MATLAB whereas the data processing of the new system was made from the post processing programs in LABVIEW.

Table 3.5.2 shows the individual values of amplitude from one observer in the temporal direction obtained with the oscilloscope (analysed by MATLAB) and LABVIEW. The third column represents the difference between those recording systems. At the bottom of each column, there is the average, standard deviation and coefficient of repeatability (1.96 * $STDEV_{DIFFERENCES}$) from all individual measurements in this specific direction. These values were calculated for all saccadic parameters in the eight directions under investigation.

Bland and Altman (1986) suggested that when the differences between two systems fall within ±1.96 * $STDEV_{DIFFERENCES}$, then the values obtained from either system are not clinically different. Therefore, those two systems could be considered as "identical".

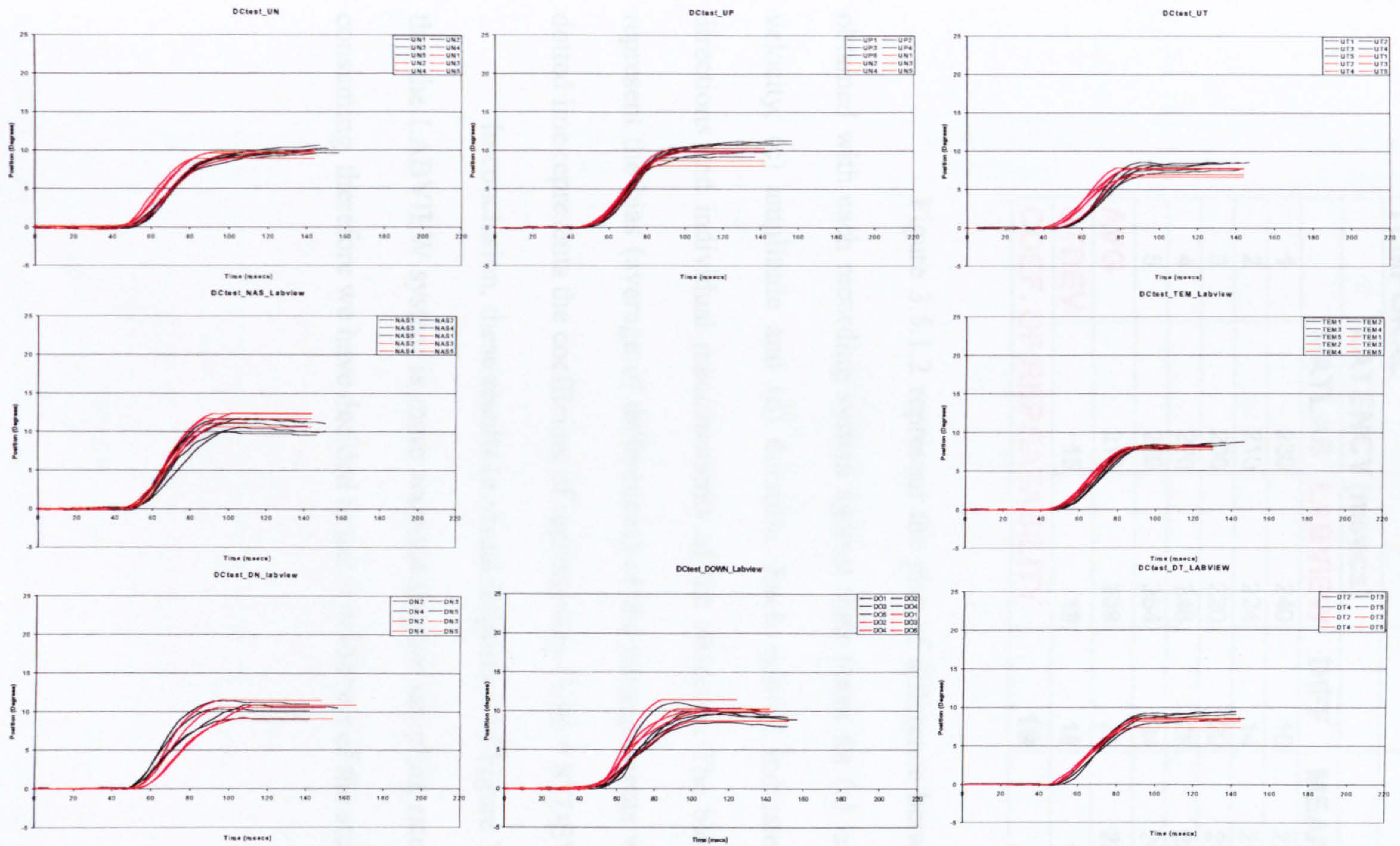


Figure 3.5.1.1: Those graphs represent the superimposed profiles of a 10° saccade from one young observed (DC) for 8 different directions. The red line represents data collected with new system (LABVIEW) and the black line the ones collected with old system (oscilloscope). The top 3 graphs represent all movements with an upward element (UN, UP, UT), the middle raw represent the horizontal directions and the bottom raw represents all the movements with a downward element (DN, DOWN, DT).

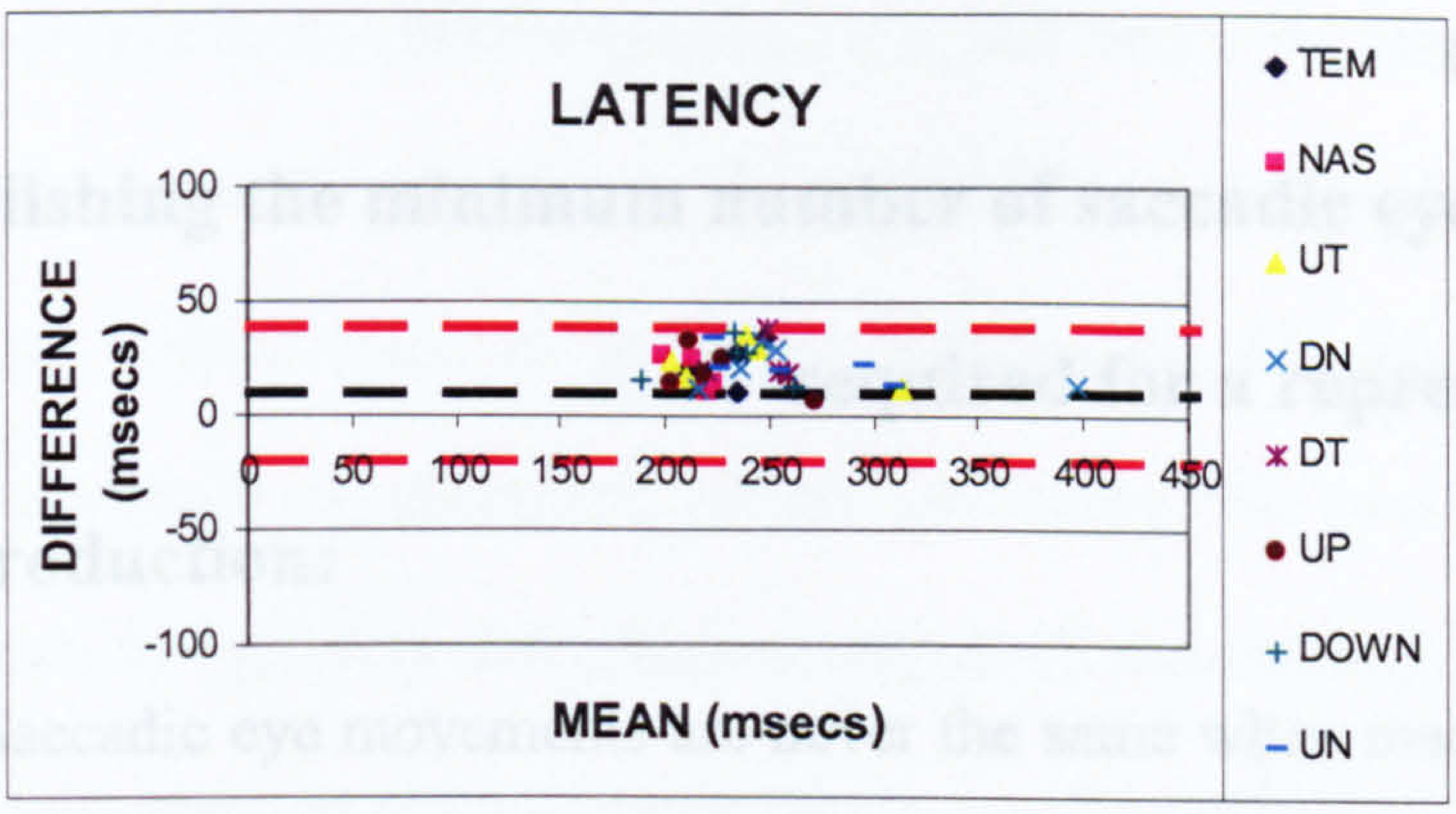
Table 3.5.2: The individual latencies for the temporal direction of one observer (DC) in the MATAB versus LABVIEW trials with intra-individual difference between the paired evaluations.

Observer DC				
TEMPORAL				
	LATENCY (msecs)			
	MATLAB	LABVIEW	DIFF	MEAN
1	230	240	10	235
2	210	224	14	217
3	200	220	20	210
4	220	248	28	234
5	230	264	34	247
AVG	218	239	21	229
STDEV	13	18	10	15
COEF. OF REPEATABILITY			19	

Figure 3.5.1.2 represent the plot of difference between the values obtained with each recording system against their mean for (a) latency, (b) peak velocity, (c) amplitude and (d) duration. Each symbol indicates the different directions and individual measurements of the observer. The black dotted lines represent the bias (average of differences) of the measurements whereas the red dotted line represents the coefficient of repeatability (1.96 * $STDEV_{DIFFERENCES}$).

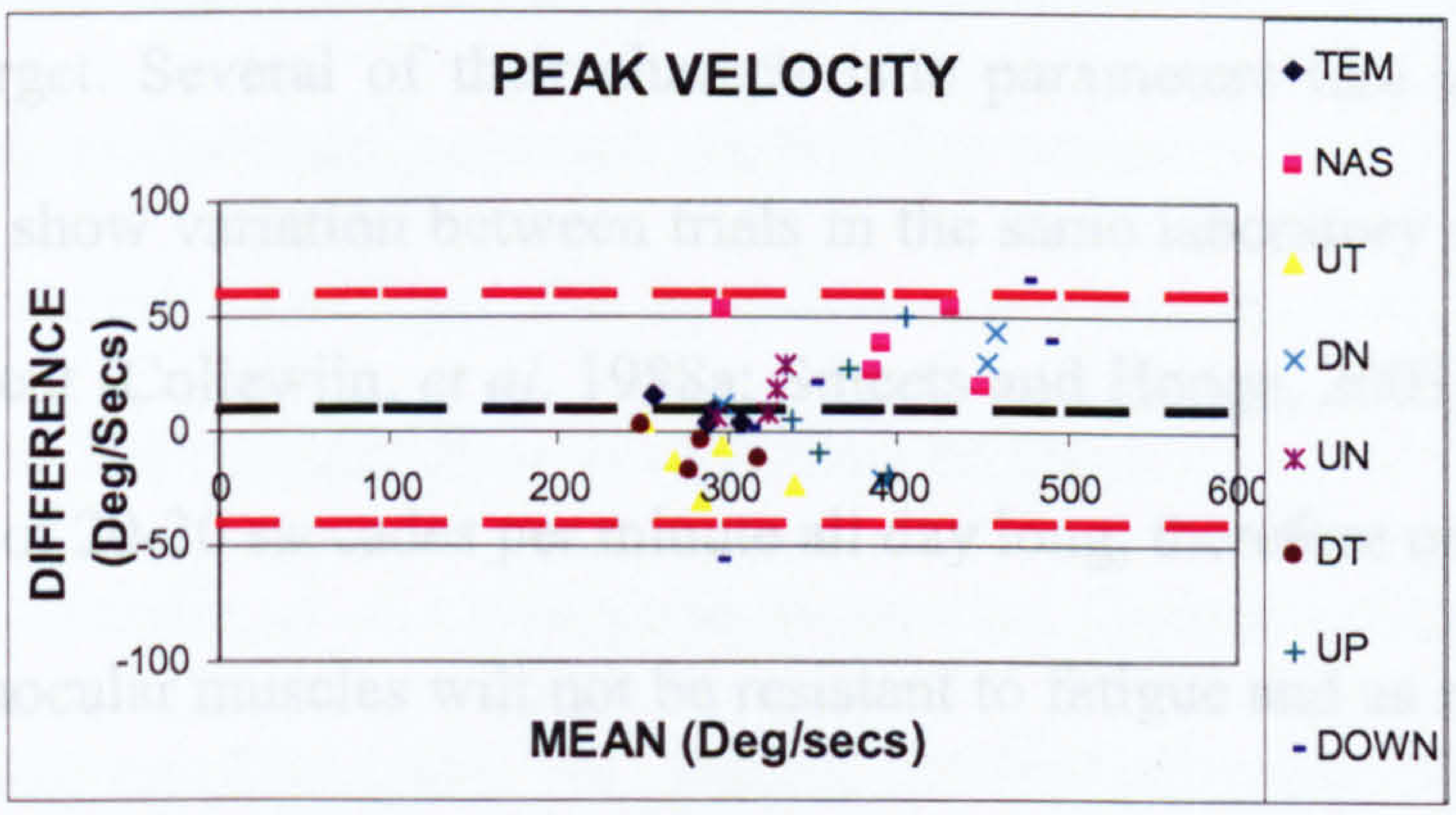
In conclusion, these results (a visual inspection of Figure 3.5.1.2) suggest that the LABVIEW system is more accurate (higher sampling rate) and less time consuming, therefore we have decided to use it in the rest of the studies.

a)



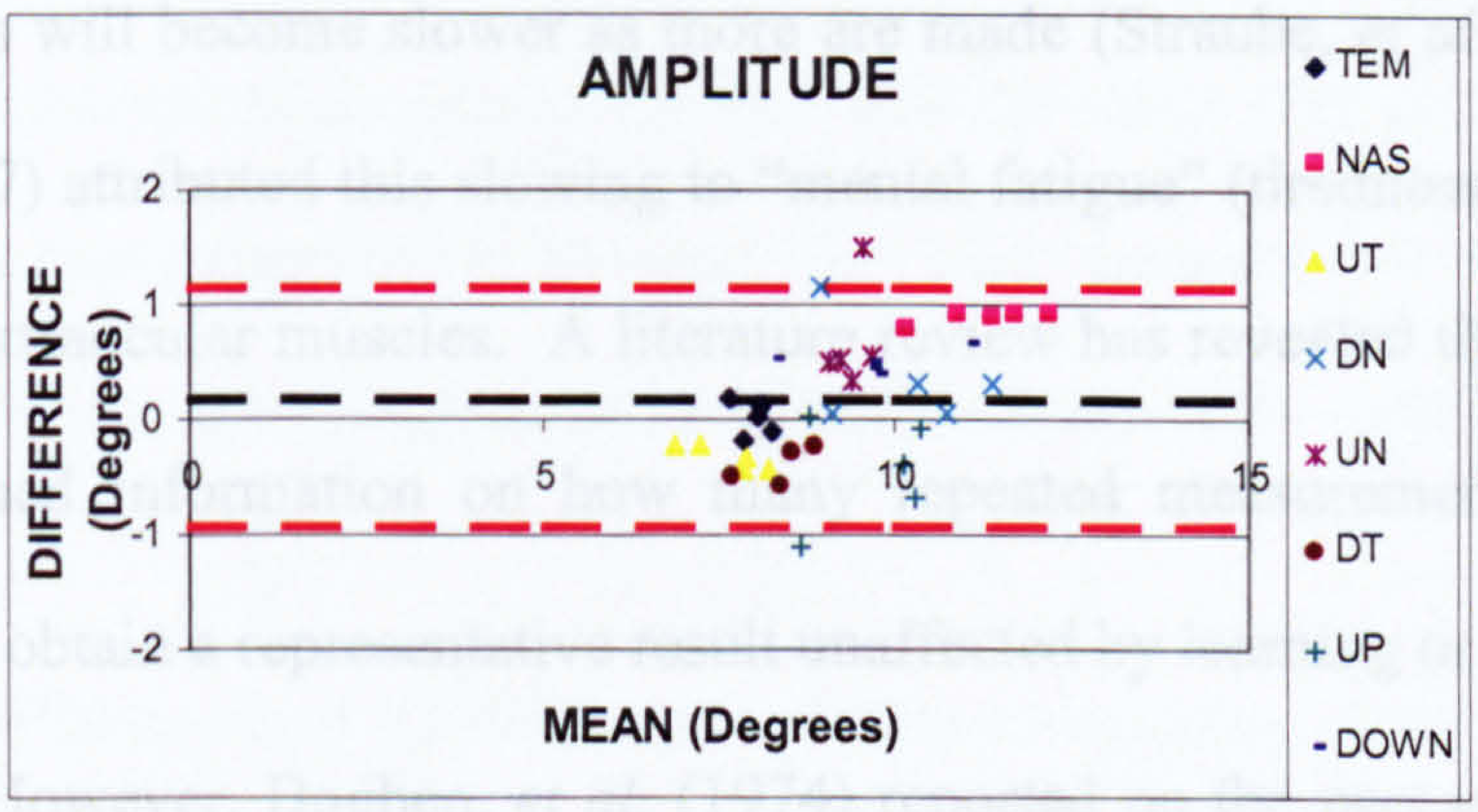
Mean Coefficient of Repeatability for Latency: ± 30 msecs

b)



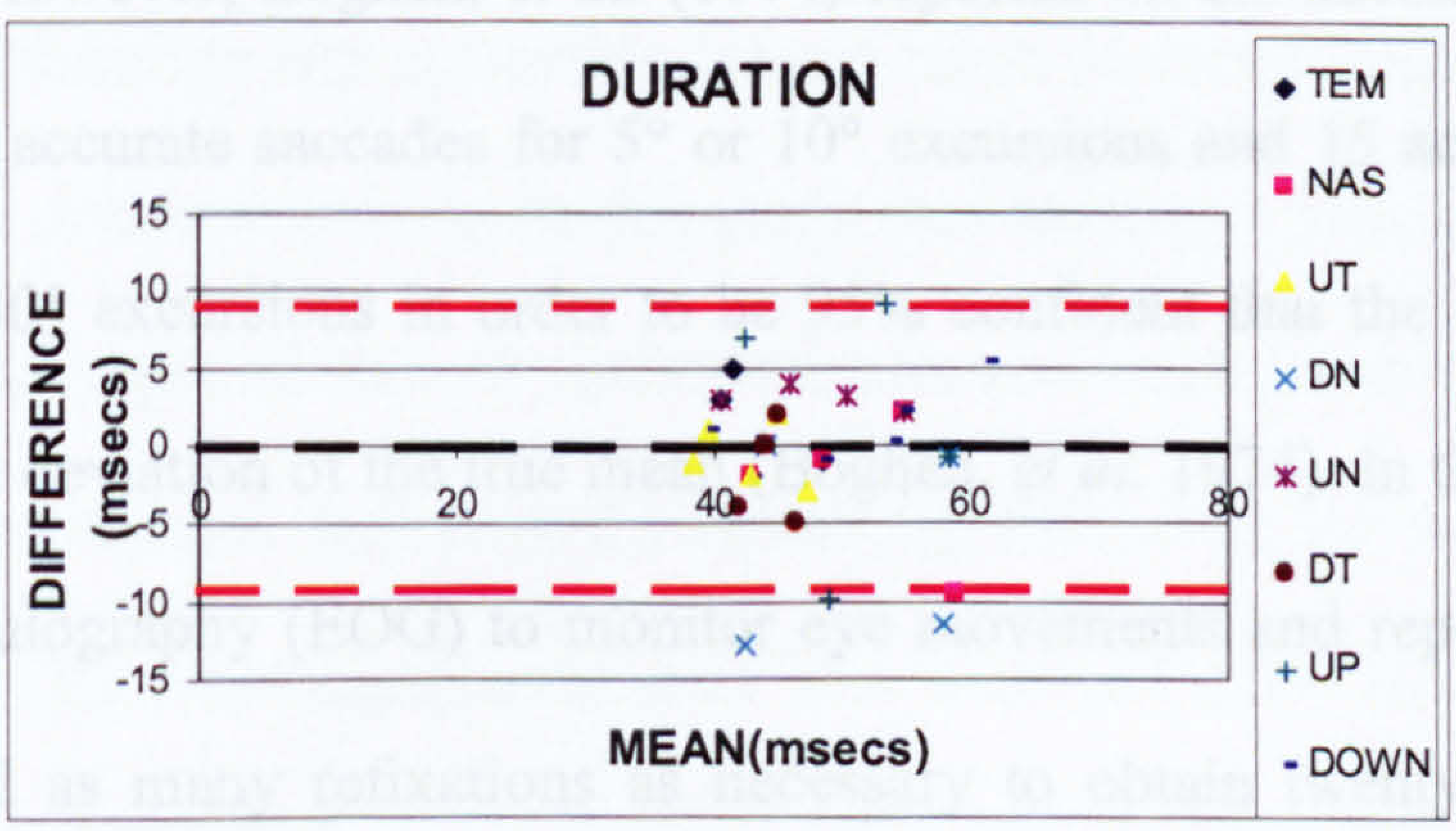
Mean Coefficient of Repeatability for Peak Velocity: ± 50 deg/secs

c)



Mean Coefficient of Repeatability for Amplitude: ± 1 deg

d)



Mean Coefficient of Repeatability for Duration: ± 9 msecs

5.1.2: These plots correspond in (a) latency, (b) peak velocity (c) amplitude (d) duration. The x-axis represents the mean between the two trials whereas the y-axis represents their differences. Each symbol characterises the different directions. The black dotted line represents the bias of the measurements whereas the red dotted lines represent the coefficient of repeatability (1.96*STDEV$_{\text{DIFFERENCE}}$).

CHAPTER 4:

Establishing the minimum number of saccadic eye measurements required for a representative result.

4.1 Introduction:

Saccadic eye movements are never the same when made repeatedly to the same target. Several of their characteristic parameters like amplitude and peak velocity show variation between trials in the same laboratory or even in the same experiment (Collewijn, *et al.* 1988a; Smeets and Hooge, 2003). Humans make an average of 20-30 saccades per minute all day long; therefore one might expect that the extraocular muscles will not be resistant to fatigue and as a consequence those saccades will become slower as more are made (Straube, *et al.* 1997). Straube, *et al.* (1997) attributed this slowing to "mental fatigue" (tiredness) instead of fatigue of the extraocular muscles. A literature review has revealed that there is no well-established information on how many repeated measurements are required in order to obtain a representative result unaffected by learning or fatigue.

However, Boghen, *et al.* (1974) reported on the necessity of averaging at least 10 accurate saccades for 5° or 10° excursions and 15 accurate saccades for 20° or 30° excursions in order to be 95% confident that the mean is within one standard deviation of the true mean (Boghen, *et al.* 1974). In this study, they used electroculography (EOG) to monitor eye movements and reported that a subject executed as many refixations as necessary to obtain twenty accurate saccades without overshoots, undershoots and/or blinks artefacts. However, they gave no explanation of why they concluded that the 10 and 15 repeated measurements were optimal.

Schmidt *et al.* (1979) suggested that it is extremely important to determine the lower limits of velocities and the intra- and inter-subject variability for monitoring improvement or detecting pathological slowing of saccades in a clinical environment (Schmidt, *et al.* 1979). In this study that an infrared reflection technique was used, they averaged 10 movements to acquire the mean of each individual. In order to examine the possible effect of short-term muscular fatigue upon the main sequence relationship (velocity-amplitude), they averaged and compared data from the first five and the last five amplitudes for all observers. Their results showed no consistent trend.

Collewijn, *et al.* (1988a and b) reported the average of only four saccades obtained in one trial when they studied the binocular coordination of horizontal and vertical saccades, despite the fact that the variability observed between and within subjects appeared to be large. This study (magnetic search coil) used fewer measurements than Boghen, *et al.* (1974) and again no justification for this was given.

Wilson, *et al.* (1993) reported that a sequence of 24 saccades could be performed before any noticeable fatigue effect occurred; therefore they recorded two sets of this sequence. In this study that an electoculographic technique was used, they reported that 48 individual saccades were recorded, but several data sets were rejected and only the remaining valid data set was used for further analysis. They did not clearly state how many of those individual values were actually averaged.

There are several reasons why the number of repeated recording measurements varies. One of the principal sources of any type of disagreement in the field of eye movements is undoubtedly the variety in the recording methods and data analysis available (Collewijn, *et al.* 1988a; Versino, *et al.* 1992; Smeets and Hooge, 2003). Another reason why is probably due to protocol restrictions. In an objective assessment of abnormal eye movements in infants and young children, Jacobs, *et al.* (1992) could roughly record 10 saccades in each amplitude Similarly, Koca *et al.* (1992), in a study on the alterations observed in patients with myotonic dystrophy, reported that the subjects made five to ten saccades under a periodic activation of the diodes since the nominal size of the saccades could not be met. Smit, *et al.* (1987) also reported that variability depends on the degree of difficulty in accomplishing a certain task. The simpler the task is the less intra- and intersubject variability is observed.

A review of the literature has revealed that in eye movement research there is no specific pattern to follow concerning the number of repeated measurements required. The aim of this study was to determine the clinical value of a non-invasive eye movement recording technique. In a clinical environment, time as well as precision is very important. Consequently, one aspect of this investigation is to establish the minimum number of measurements required in one session without compromising the precision of our recordings. This approach has previously been considered by Douthwaite and Jenkins (1988) in relation to the number of responses required for a representative visually evoked response. A good clinical test must be repeatable with good precision from a quickly achieved measurement. In many cases a compromise must be reached where high precision is achieved only after averaging many measurements.

4.2 Methods

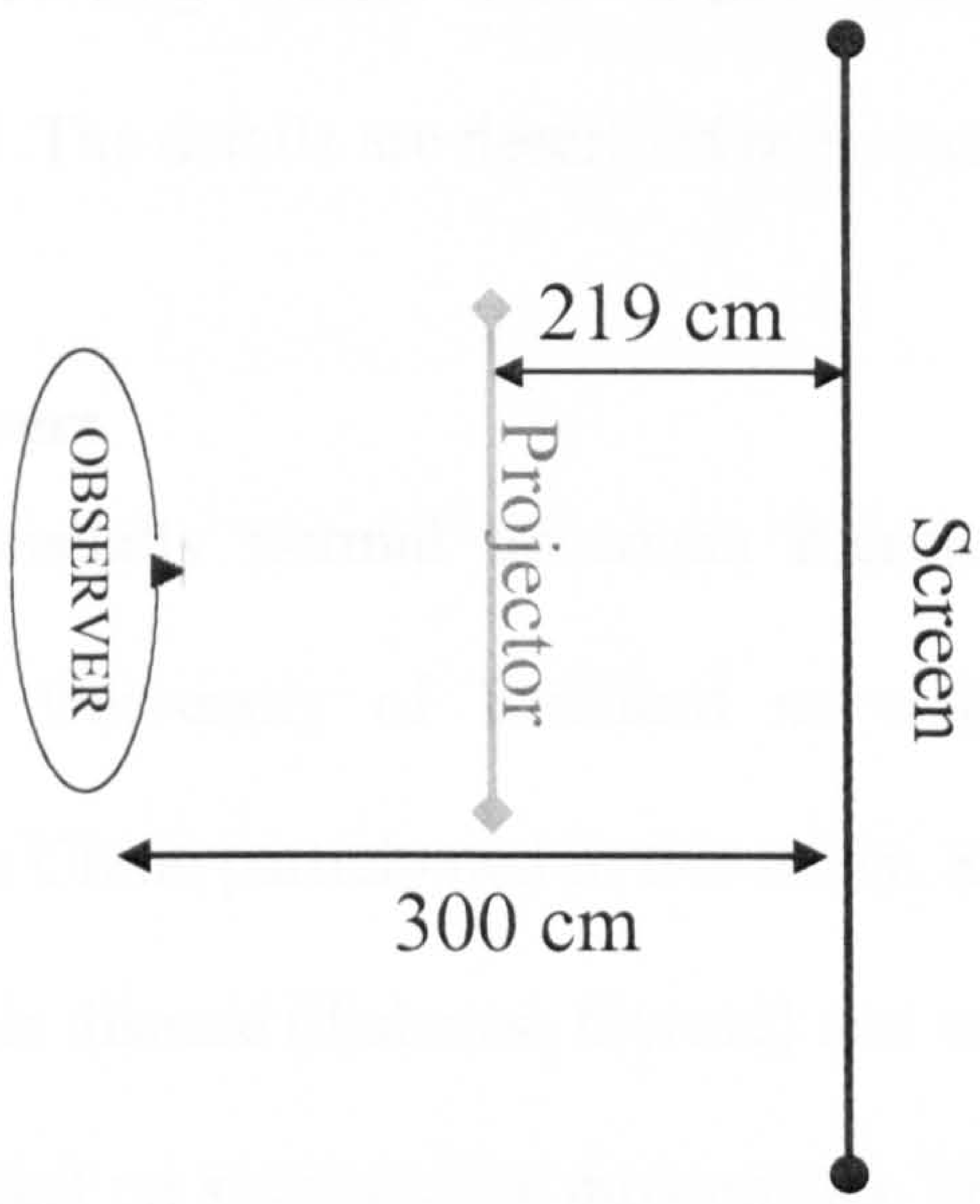
4.2.1 Stimulus

The stimulus is a white square point (3×3pixels) moving in different directions, horizontal (180°), vertical (90°) and oblique (45°-135°). It is generated using PRESENTATION software and presented to the observer through a projector system (SANYO PLC-XU33). The resolution of the monitor used was 1024×768 pixels. The projected image was contained within a black rectangular screen with a horizontal extent of 192 cm and vertical one of 143 cm (Figure 4.2.1.b).

The distances between the observer and the screen (300 cm) as well as between the projector and the screen (219 cm) were selected (Figure 5.2.1.a) in order to establish an angular displacement of 15° for horizontal measurements, 10° for vertical and 15° for the oblique measurements of the visual field from the primary position.

At the viewing distance, this set up resulted of 5.7 minarc visual angle for our stimulus. The contrast of the stimulus was 99.5%. This value was calculated by using the same formula as in Chapter three. Our measured luminance values were $L_{stimulus}$ = 139.2 cd/m^2 for the stimulus and $L_{background}$ = 0.296 cd/m^2 for the background.

a)



b)

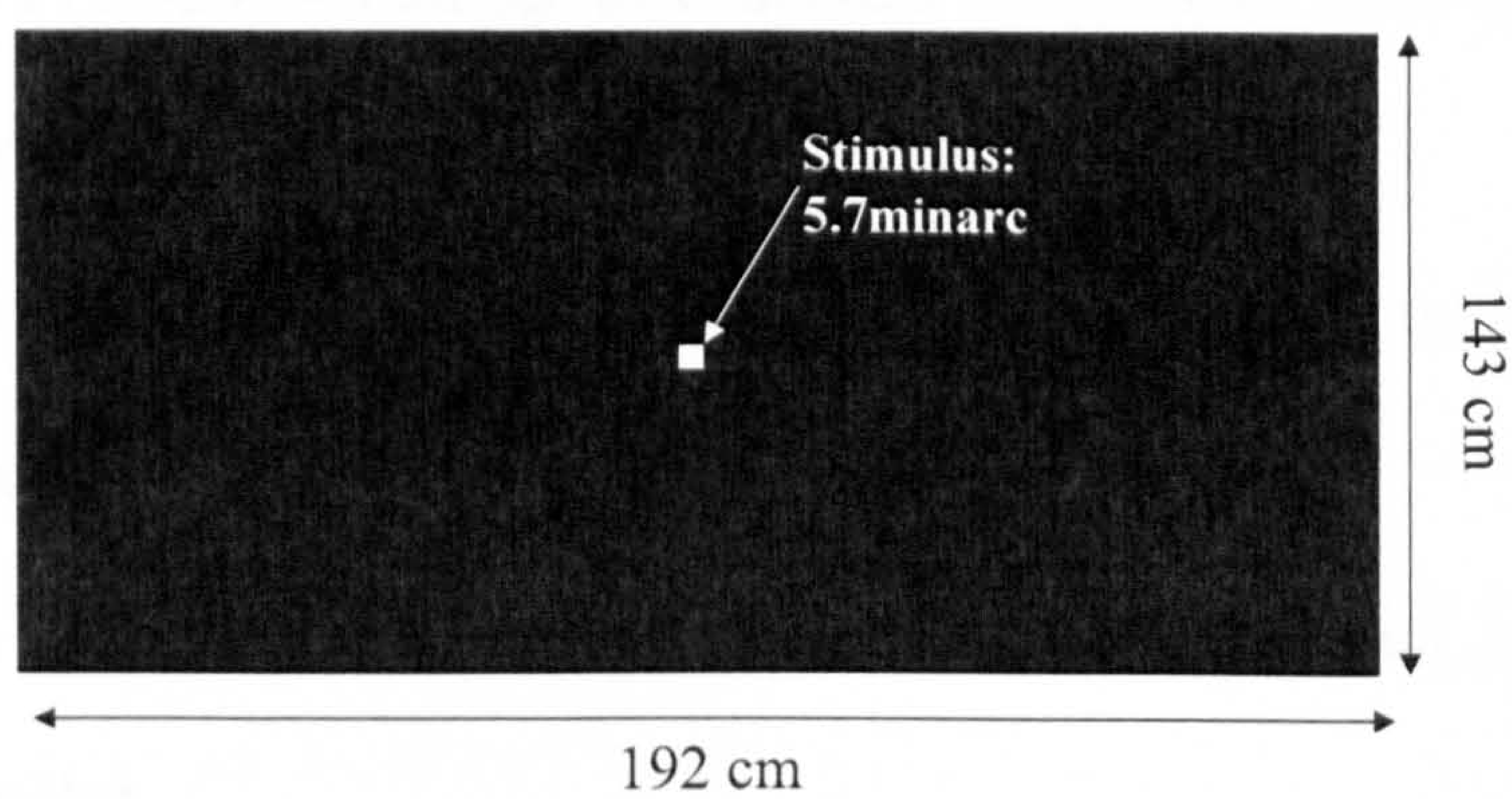


Figure 4.2.1:Schematic diagram of the set up system showing the distances between the observer and the screen (300cm) and between the projector and the screen (219cm).

4.2.2 Eye movement monitoring apparatus.

The recording apparatus used in this experiment was an infrared light eye tracker (IRIS 6500). The eye tracker uses a method based on the reflection of infrared radiation by the iris-sclera boundary of the eye (Skalar Medical, Delft, The Netherlands). The details were previously described in Chapter three.

4.2.3 Recording system

The recording system used in this study consisted of a laptop running LABVIEW 6.1.The details are described previously in section 3.4.

4.2.4. Observers

Sixty visually normal observers recruited from the staff and student population of University of Bradford as well as the volunteers' from the University Eye Clinic participated in this study. Subjects participating in the study had no systemic disease (diabetes, thyroid) and were not under medication known to have any effect on saccadic eye movements. The volunteers were separated into 3 different age groups:

- Group I (20-39) = number of observers 20 (median 25.5, range 20 to 39, 11 Female)
- Group II (40-59) = number of observers 20 (median 46, range 40 to 59, 10 Female)
- Group III (60-89) = number of observers 20 (median 69.5, range 60 to 80, 11 Female)

Prior to the collection of eye movement data, all subjects underwent a series of preliminary optometric tests (LogMAR visual acuity, cover test, motility and stereopsis) to establish that their binocular vision was normal. All subjects demonstrated a TNO stereoscopic acuity better than 60 min arc. Visual acuity in all observers was at least 0.0 LogMAR. An optical correction was used if necessary in the form of the subjects' own contact lenses or full aperture trial case lenses.

4.2.5 Experimental procedure

Monocular recordings were carried out in a darkened room and observers fixated on the white square target at a viewing distance of 300 cm. The eye with the best visual acuity or the dominant eye was selected in each individual. The action of the extraocular muscle was used to classify the directions under investigation. For example, the horizontal to the right movement, with respect to the subject, was identified as the temporal direction for the right eye and the nasal direction for the left eye respectively.

A chinrest was used to reduce head movements and target height was adjusted to ensure that the target and the observer's eyes were at the same level. The appropriate adjustments in the setting of the eye tracker were followed as described in Chapter three.

The whole experimental procedure was separated into four trials. Each trial consisted of a pair of directions with their calibration sequence. Between these trials, subjects had short breaks in order to avoid the effect of fatigue and to allow the sensors and stimulus to be reset for the next trial. The order of presentation was randomised between and within the trials of each observer in order to avoid possible effects of fatigue.

Prior to any data collection, instructions were given to the observers. The observers knew the direction that the stimulus would take. For the calibration sequence we indicated when the stimulus was going to move. In contrast, during data recording, we activated the stimulus with a random delay without indicating when the stimulus was going to move. Therefore the subjects were instructed to expect a stimulus movement at any time. This difference was due to the fact that during the calibration sequence we were interested to see if the sensors of the eye tracker were properly set and not on the actual saccadic profile.

4.2.6 Data processing

The data processing in this study is identical to the one described in Chapter three (section 3.4.1).

4.3 Results

Due to the initial data processing, we were able to obtain individual values for each saccadic parameter (latency, duration, peak velocity and amplitude) in all the eight directions under investigation for all the subjects. During the intra-subject analysis there were data points, which were disregarded due to the effect of anticipation (negative latencies) and/or contamination from blinks. These appeared in the analysis as missing data. In a typical measurement an average of 3 missing data per observer could occur. The same individual analysis was applied to all 60 observers in the 3 age groups.

4.3.1 Group I (20-39 years)

4.3.1.1 Latency:

Figure 4.3.1.1.1 represents the group mean latencies obtained for the 20 subjects in this age group for the 10 runs in all directions. Each point on the graph is the group mean arising from the twenty individual subject values for each run (one saccade). The bars show the standard deviation, which represents the intersubject variability within each run.

The statistical package that was used to analyse this set of data was SPSS 11 for Windows. A repeated measures analysis of variance (ANOVA) was applied in each of the eight different directions separately. The individual runs were selected as the within-subject factor.

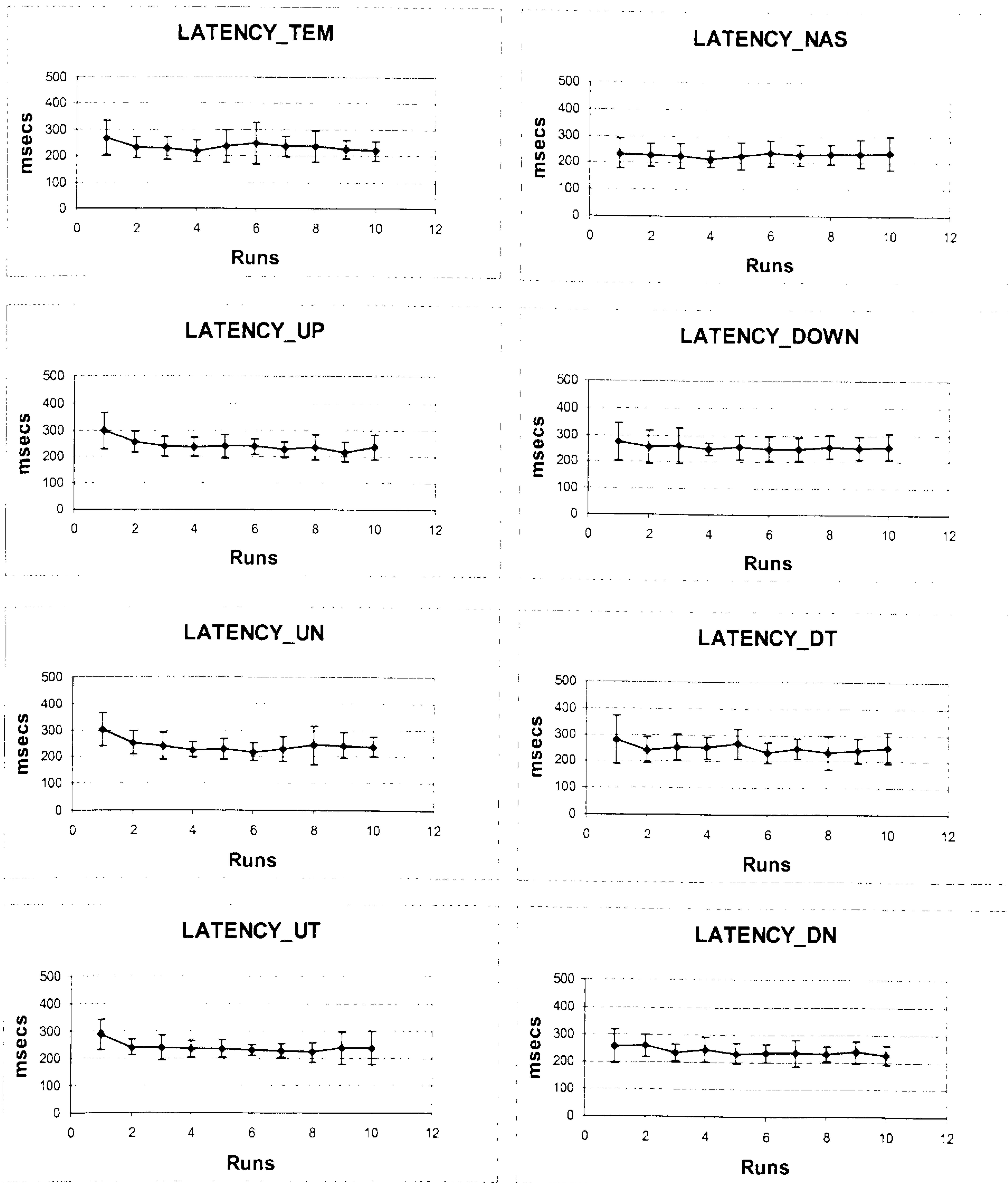


Figure 4.3.1.1.1: Each point on the graph represents the group mean obtain from the twenty individual subject measurements for latency. The error bars show the standard deviations for each run.

Table 4.3.1.1.1 shows a summary of those ANOVA results for each direction respectively.

Table 4.3.1.1.1: Repeated measurements ANOVA results for the individual runs.

Directions	ANOVA results (Individual runs)
TEM	F (9,153) = 2.15, p = 0.19
NAS	F (9,153) = 0.68, p =0.73
* UP	**F (9,135) = 2.38, p< 0.001**
DOWN	F (9,117) = 0.62, p =0.78
* UN	**F (9, 117) = 4.65, p =0.001**
DT	F (9,135) = 2.71, p =0.25
* UT	**F (9,126) = 6.21, p =0.006**
DN	F (9,135) =2.20, p =0.24

All directions apart from the ones with an upward component (UP, UN, UT) showed no significant difference (p>0.05) within the group between any of the ten runs. In the up direction, pairwise comparisons between the ten runs revealed that the mean latency of the first run was significantly different to the ninth run (p = 0.03). In addition, the statistical analysis revealed a highly significant difference across the ten runs in the UN direction. Pairwise comparisons between the individual runs showed that the first run was significantly different to the fourth (p = 0.04), fifth (p = 0.008), sixth (p = 0.009) and the seventh run (p = 0.003).

There appears to be no within trend arising from factors such as fatigue, learning or changes in attention. The standard deviations indicate the overall intersubject variability. The mean and the standard deviations in each direction shown in Figure 4.3.1.1.1 are summarised in Table 4.3.1.1.2. These values give an indication of the latency variation arising during measurements. A supplementary way to present this variation and the link between the mean and the standard deviation is the coefficient of variation. These values appeared to be similar among all the eight directions.

Table 4.3.1.1.2: Mean latencies, standard deviations and coefficient of variation for all individual 10 runs and 20 observers in each direction separately.

Directions	*Mean Latency (msecs) (Group mean)*	*Stdev*	*Coefficient of variation %*
TEM	235	± 33	14
NAS	229	± 32	14
UP	242	± 25	11
DOWN	255	± 31	12
UN	243	± 30	13
DT	250	± 38	15
UT	240	± 23	10
DN	239	± 28	12
AVERAGE FOR ALL DIRECTIONS	**242**	**± 30**	**13%**

As mentioned previously, the group mean latencies illustrated in Figure 4.3.1.1.1 show no statistically significant change across the ten runs for the eight directions. It is therefore reasonable to assume that the most accurate representation of latency will arise from averaging all ten runs. If this is accepted then it will be informative to compare the average of all ten runs with the one deduced from nine runs, eight runs, seven runs, six runs, five runs, four runs, three runs, two runs and one run respectively. We can work back from the ten run average towards the single run to determine where the latency changes significantly.

Figure 4.3.1.1.2 represents these running averages so that run number one is the average of the 20 subjects (20 data values), run number two is the average of run one and two (40 data values) and run number ten is the average of 200 data values. A visual inspection of Figure 4.3.1.1.2 reveals an early progressive reduction in latency as more runs are averaged after which the latency value appears stable. Since no trend has been established for the individual ten runs, the progressive reduction in mean latency and its standard deviation is most likely due to the increasingly effective elimination of random variation.

A repeated measurement ANOVA revealed a non-significant difference across the ten running averages in most of the directions (Table 4.3.1.1.3).

Table 4.3.1.1.3: Repeated measurements ANOVA results for the running averages.

Directions	**ANOVA results** (Running averages)
TEM	$F_{(9,171)} = 7.10, p = 0.20$
NAS	$F_{(9,171)} = 0.84, p = 0.58$
UP	$F_{(9,153)} = 12.09, p = 0.23$
DOWN	$F_{(9,153)} = 1.21, p = 0.29$
* **UN**	**$F_{(9,171)} = 24.58, p < 0.001$**
DT	$F_{(9,162)} = 4.49, p = 0.10$
* **UT**	**$F_{(9,171)} = 14.26, p < 0.001$**
DN	$F_{(9,162)} = 3.62, p = 0.12$

In the case of up nasal (UN), there is a significant difference ($F_{9,171} = 24.58$, $p < 0.001$). A pairwise comparison revealed that the first four running averages are significantly different from the remaining ones. The other direction that also indicated a significant difference among the ten runs was the up temporal (UT) ($F_{9,171} = 14.26$, $p<0.001$). In this direction only the first three averages were significantly different from the remaining ones. Thus ANOVA suggests that the running averages of latency are representative after the merging of four runs but this may be an oversimplification. The results apply to the group and may possibly be unrepresentative when compare to the latency variation in an individual subject.

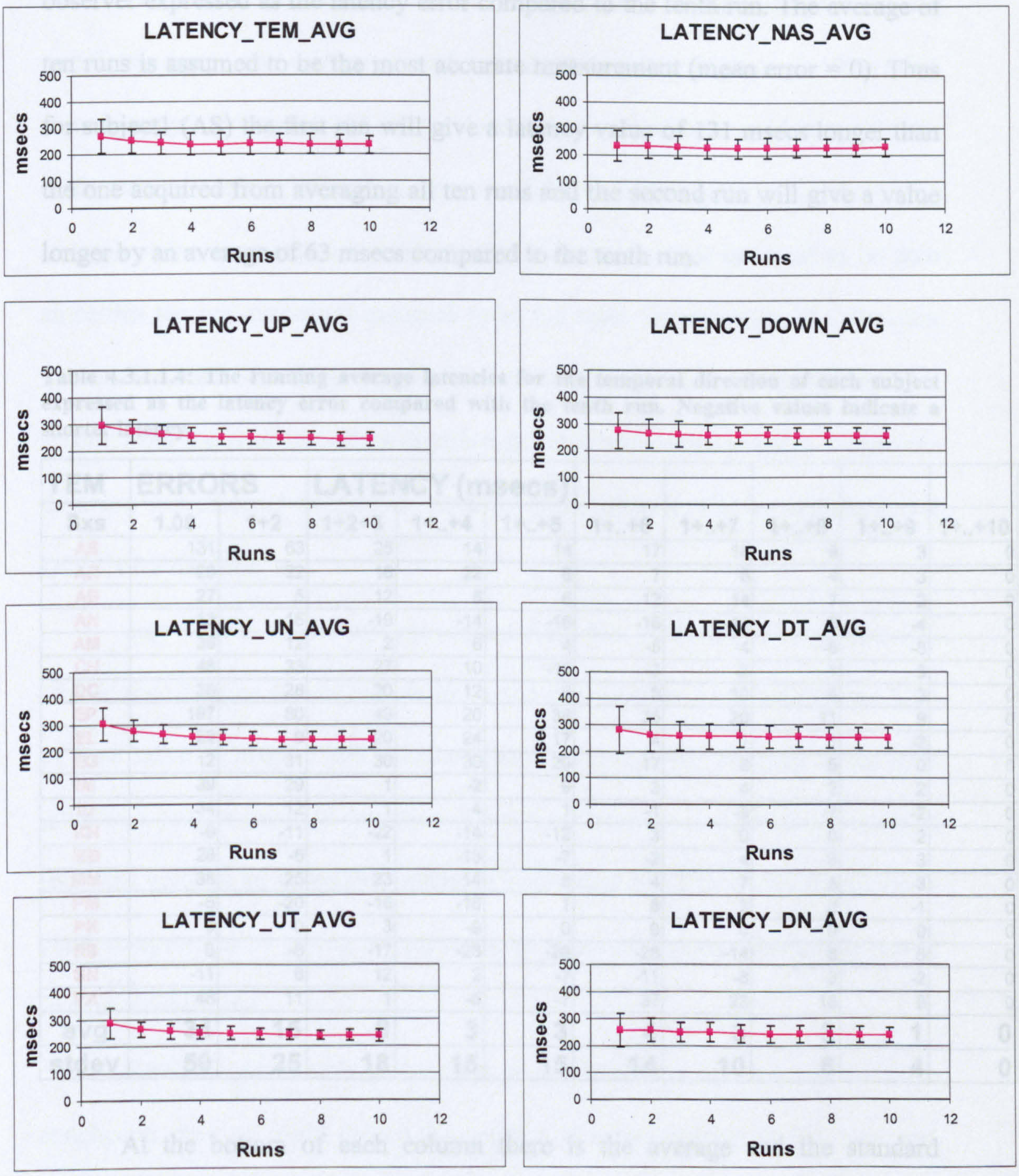


Figure 4.3.1.1.2: Running averages for latency in Group I (20-35 years). Each point on these graphs are the group mean obtaining from the twenty individual measurements for latency. Run number one is the group mean arising from 20 data values, run number two is the average of 40 and run number ten is the average of 200 data values. The error bars show ±1 STDEV for each run.

An alternative approach to the data was also considered. Table 4.3.1.1.4 shows the running average latencies error for the temporal direction of each observer expressed as the latency error compared to the tenth run. The average of ten runs is assumed to be the most accurate measurement (mean error = 0). Thus for subject1 (AS) the first run will give a latency value of 131 msecs longer than the one acquired from averaging all ten runs and the second run will give a value longer by an average of 63 msecs compared to the tenth run.

Table 4.3.1.1.4: The running average latencies for the temporal direction of each subject expressed as the latency error compared with the tenth run. Negative values indicate a shorter latency.

TEM	ERRORS		LATENCY (msecs)							
Sxs	**1.00**	**1+2**	**1+2+3**	**1+..+4**	**1+..+5**	**1+..+6**	**1+..+7**	**1+..+8**	**1+..+9**	**1+..+10**
AS	131	63	25	14	14	17	16	9	3	0
AR	20	22	16	22	8	7	6	4	3	0
AB	27	5	12	6	6	12	14	7	2	0
AN	-13	-15	-19	-14	-16	-16	-13	-5	-4	0
AM	36	12	2	6	4	-5	-4	-8	-8	0
CH	48	33	27	10	-13	-3	-2	1	3	0
DC	38	28	20	12	6	5	10	4	3	0
EP	197	80	49	20	38	26	20	11	9	0
EL	22	9	20	24	17	4	1	1	-2	0
EG	12	31	30	30	29	17	8	5	0	0
IM	39	29	1	-2	9	3	4	3	2	0
IU	34	12	1	4	1	-1	-5	-7	-2	0
KH	-9	-11	-22	-14	-12	3	0	0	2	0
MB	28	-6	1	-13	-7	-2	4	5	3	0
MM	38	25	23	14	8	4	7	5	3	0
PM	-5	-20	-16	-16	1	8	3	2	-1	0
PK	0	0	3	-9	0	0	0	0	0	0
RS	6	-6	-17	-28	-28	-28	-14	8	5	0
SN	-11	6	12	2	-7	-11	-8	3	-2	0
VA	48	11	1	-5	-7	37	23	16	8	0
avg	**34**	**15**	**8**	**3**	**3**	**4**	**3**	**3**	**1**	**0**
stdev	**50**	**25**	**18**	**15**	**15**	**14**	**10**	**6**	**4**	**0**

At the bottom of each column there is the average and the standard deviation of errors obtained from all subjects in that specific run. Run number one is the group mean arising from 20 data values, run number two is the average of 40 and run number ten is the average of 200 data values. These values may help to create an overall picture.

From these data we can see that for the forth running average there is a population mean error of 3 msecs and a standard deviation of 15 msecs. The mean error increases to 4 msecs and the standard deviation decreases to 14 msecs for the sixth running average. The mean latency of this direction is 235 seconds for the average of ten measurements with a population mean error assumed to be zero since this ten run average is assumed to be the most accurate one. The direction chosen for Table 4.3.1.1.4 was selected at random. In order to avoid any bias arising from the selection of the direction in subsequent similar tables, a different direction was selected as follows: NAS for peak velocity, UP for amplitude and DOWN for duration, etc.

Any worker in the eye movement field has to decide how precise one wishes their latency measurements to be and this must be considered in the light of time taken to acquire and calculate them. Although the merging of six runs gives us a smaller standard deviation of error, we have decided that the average of four runs gives us an acceptable precision in this data set. This decision provides a good compromise by giving a representative value of latency, which is achieved in a reasonable time.

Similarly, we examined the other seven directions and came to the same conclusion, that we could reduce the number of measurements to four runs and thereby acquire a representative result. Table 4.3.1.1.5 compares the running average of four runs to that of six runs.

The analysis described above for the assessment of latency was applied to the other saccadic parameters, namely peak velocity, amplitude and duration. In all cases there was little if any evidence of trends towards increasing or decreasing values over a ten-measurement procedure. The averaging of four measurements appeared to be appropriate in order to achieve a representative results in the minimum recording time. To support this proposal each measurement analysis ends with a table comparing the average mean error of four runs to the average of six runs. A comparison will then be made in the discussion section of this Chapter.

Table 4.3.1.1.5: Comparison between the running average of four runs to that of six runs for all eight directions.

Direction	Mean latency (msecs)	AVG of 10runs		AVG of 4 runs		AVG of 6runs	
		Mean error	Stdev error	Mean error	Stdev error	Mean error	Stdev error
TEM	235	0.00	0.00	3	15	4	14
NAS	229	0.00	0.00	-3	17	-2	12
UP	242	0.00	0.00	13	15	8	7
DOWN	255	0.00	0.00	4	15	2	9
UN	243	0.00	0.00	13	14	3	11
DT	250	0.00	0.00	6	21	4	13
UT	240	0.00	0.00	11	15	5	11
DN	239	0.00	0.00	10	14	5	11
			Average all directions	**7**	**16**	**3**	**11**

4.3.1.2 Peak Velocity:

The same analysis (as for the data set of latency) was also followed in this saccadic parameter for the young age group. Figure 4.3.1.2.1 shows the group mean peak velocity for the 20 subjects in the young age group for all 10 runs in all the directions under investigation.

A repeated measures ANOVA was applied in all eight directions for the individual runs separately. Table 4.3.1.2.1 summarizes the results of those individual runs ANOVA results for each direction.

Table 4.3.1.2.1: Repeated measurements ANOVA results for the individual runs.

Directions	ANOVA results (Individual runs)
TEM	F (9,153) = 1.01, p = 0.39
NAS	F (9,153) = 1.08, p = 0.38
UP	F (9,135) = 0.72, p = 0.69
DOWN	F (9,117) = 2.52, p = 0.07
UN	F (9.117) = 1.41, p = 0.19
DT	F (9,135) = 1.68, p = 0.10
UT	F (9,126) = 1.73, p = 0.09
DN	F (9,135) = 1.31, p =0.24

All directions showed no significant difference ($p>0.05$) within the group between any of the ten runs.

The mean and the standard deviations in each direction shown in Figure 4.3.1.2.1 are summarised in Table 4.3.1.2.2. These values give an indication of the peak velocity variation arising during measurements.

Table 4.3.1.2.2: Group mean peak velocities, standard deviations and coefficient of variation for all individual 10 runs and 20 observers in each direction separately.

Directions	*Mean Peak Velocity (Deg/sec) (Group mean)*	*Stdev*	*Coefficient of variation %*
TEM	402	± 151	37
NAS	318	± 74	23
UP	272	± 80	29
DOWN	286	± 58	20
UN	289	± 94	33
DT	317	± 65	20
UT	345	± 81	23
DN	299	± 71	24
AVERAGE FOR ALL DIRECTIONS	**316**	**± 84**	**26 %**

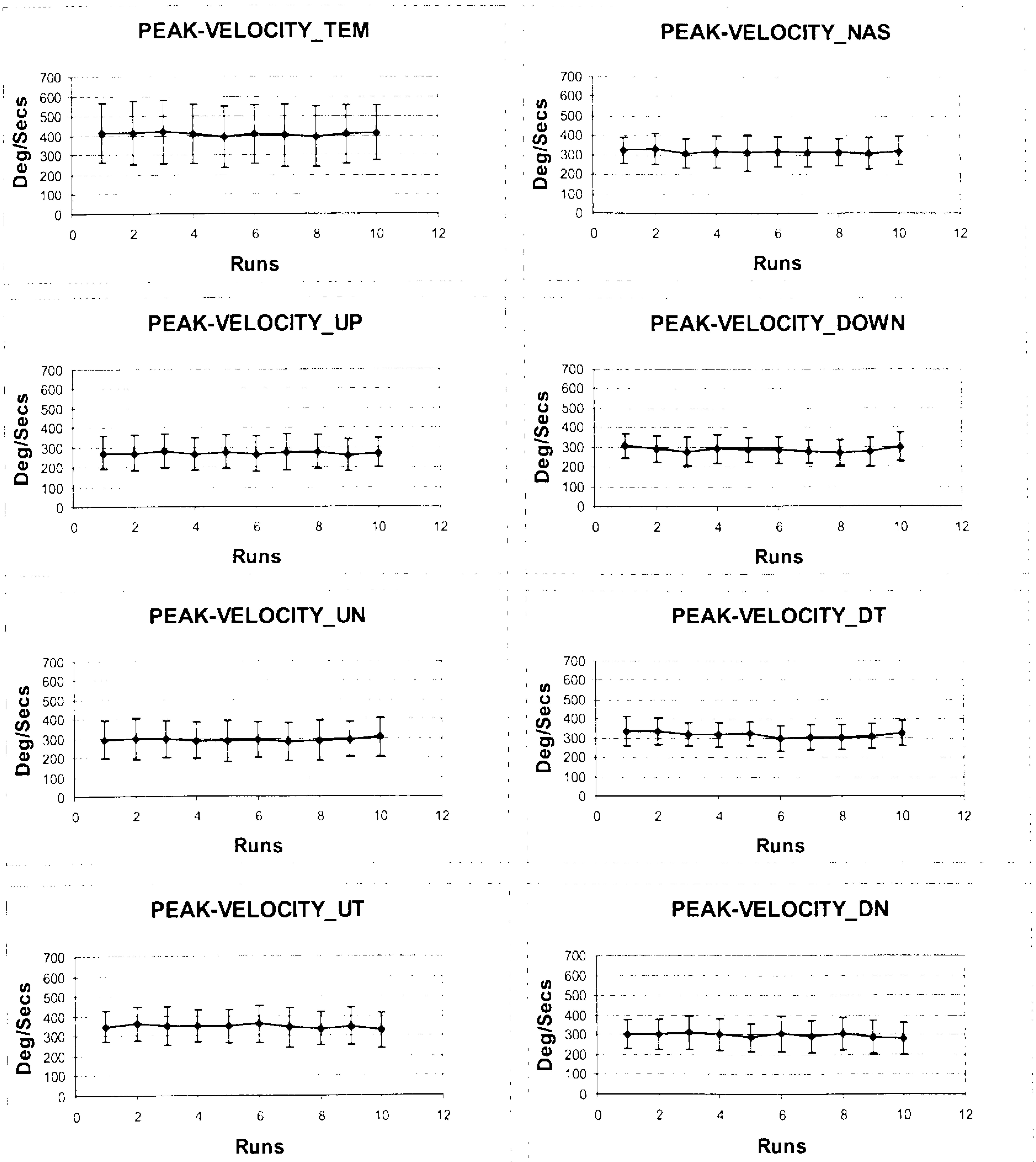


Figure 4.3.1.2.1: Each point on the graph represents the group mean obtain from the twenty individual subject measurements for peak velocity. The error bars show the standard deviations for each run.

Figure 4.3.1.2.2 represents the running averages. A visual inspection of Figure 4.3.1.2.2 reveals a stable peak velocity even from the first run in some directions.

A repeated measurement ANOVA also revealed a non-significant difference across the averaged ten runs in all the directions under investigation except one (DT) (Table 4.3.1.2.3).

Table 4.3.1.2.3: Repeated measurements ANOVA results for the running averages.

Directions	**ANOVA results** (Running averages)
TEM	F (9,171) = 2.30, p =0.07
NAS	F (9,171) = 0.95, p = 0.48
UP	F (9,135) = 0.47, p = 0.89
DOWN	F (9,153) = 2.59, p = 0.11
UN	F (9,171) = 0.84, p = 0.58
* **DT**	**F (9,162) = 2.19, p= 0.03**
UT	F (9,171) = 0.60, p = 0.79
DN	F (9,162) = 0.46, p = 0.90

In the case of down temporal (DT) there is a significant difference across the ten running average that is not verified from a further pairwise comparison. Figure 4.3.1.2.2 and the ANOVA suggest that the running averages of peak velocities are representative even with only one recording.

Table 4.3.1.2.4 shows the running average peak velocities error for the nasal direction of each observer expressed as the peak velocity error to the tenth run. The tenth run is assumed to be the most accurate measurement (mean error = 0). Therefore the first subject (AS) will give a peak velocity value higher by 5 deg/sec in the first and second run than the one acquired from averaging all the ten runs. In contrast, our second observer (AR) will give a peak velocity value lower by 9 deg/sec in the first and second run than the one acquired from averaging all the ten runs.

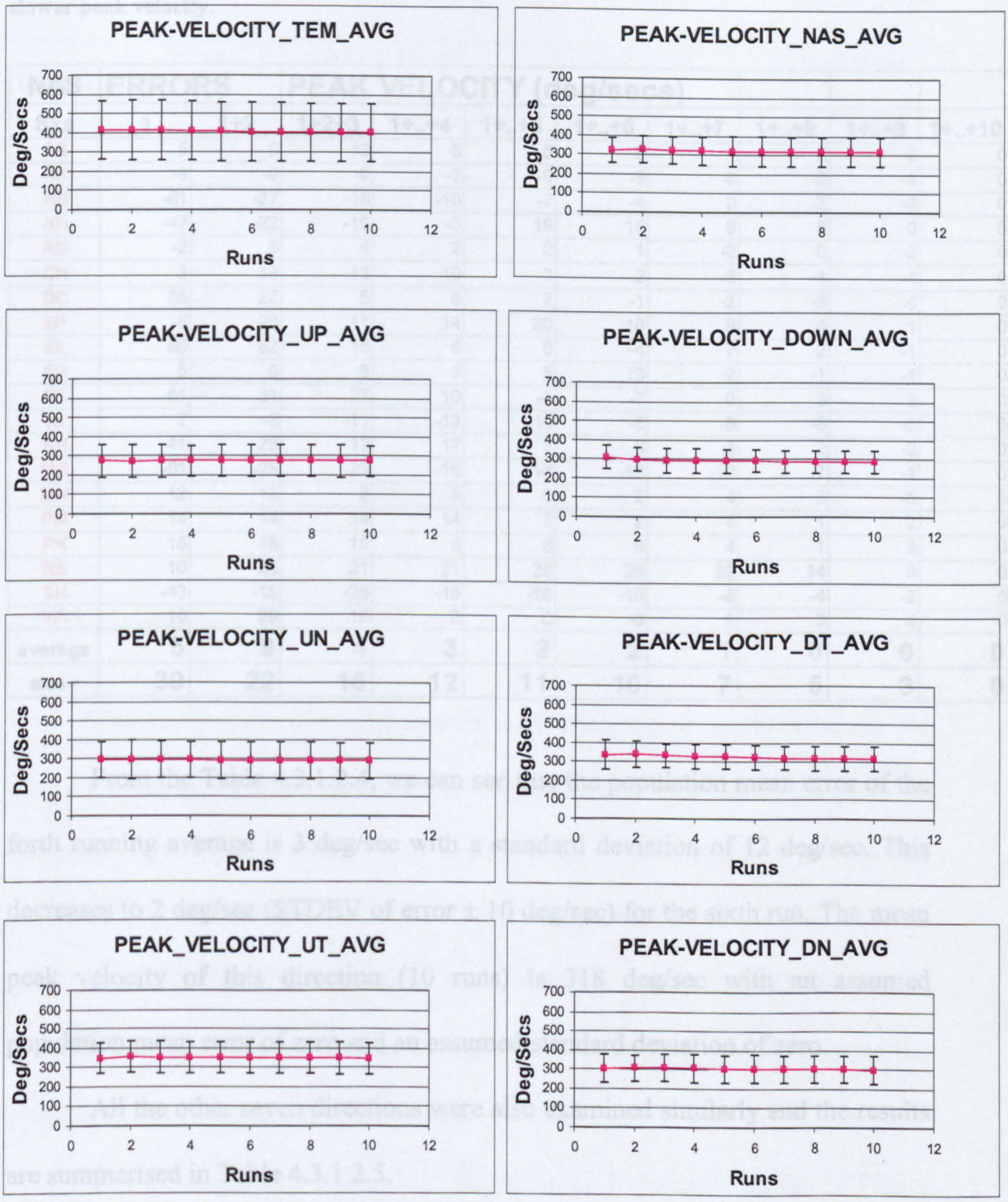


Figure 4.3.1.2.2: Running averages for peak velocity. Each point on these graphs are the group mean obtaining from the twenty individual measurements for peak velocity. Run number one is the group mean arising from 20 data values, run number two is the average of 40 and run number ten is the average of 200 data values. The error bars show the standard deviation for each run.

Table 4.3.1.2.4: The running average peak velocities for the nasal direction of each subject expressed as the peak velocity error compared with the tenth run. Negative values indicate a slower peak velocity.

NAS	ERRORS		PEAK VELOCITY (deg/secs)							
Sxs	**1**	**1+2**	**1+2+3**	**1+..+4**	**1+..+5**	**1+..+6**	**1+..+7**	**1+..+8**	**1+..+9**	**1+..+10**
AS	5	5	13	5	5	5	1	2	2	0
AR	-9	-9	-9	-3	-9	-9	-6	-3	-4	0
AB	-61	-27	-16	-10	-7	-4	0	-2	-3	0
AN	-47	-22	-10	-3	16	15	9	5	0	0
AM	-2	6	4	2	2	1	-2	0	-2	0
CH	3	18	13	10	3	-2	-6	-4	-4	0
DC	56	22	5	5	2	-1	-2	-3	-4	0
EP	-5	20	11	14	20	16	9	4	1	0
EL	90	62	15	6	0	-4	2	2	-1	0
EG	5	5	5	5	5	13	-2	-1	-1	0
IM	61	31	27	10	-4	-7	0	3	2	0
IU	2	-8	-11	-13	-10	-5	-9	-8	-5	0
KH	41	29	17	17	7	5	3	2	-2	0
MB	-61	-25	-25	-16	-18	-13	-10	-7	-1	0
MM	12	12	2	5	0	2	4	5	-5	0
PM	14	14	14	14	7	2	4	1	2	0
PK	15	15	15	6	8	9	4	1	3	0
RS	10	26	21	31	26	26	22	14	8	0
SN	-43	-15	-25	-15	-15	-10	-6	-4	-2	0
VA	16	29	16	3	0	-6	1	3	4	0
average	**5**	**9**	**4**	**3**	**2**	**2**	**1**	**0**	**0**	**0**
stdev	**39**	**22**	**15**	**12**	**11**	**10**	**7**	**5**	**3**	**0**

From the Table 4.3.1.2.4, we can see that the population mean error of the forth running average is 3 deg/sec with a standard deviation of 12 deg/sec. This decreases to 2 deg/sec (STDEV of error ± 10 deg/sec) for the sixth run. The mean peak velocity of this direction (10 runs) is 318 deg/sec with an assumed population mean error of zero and an assumed standard deviation of zero.

All the other seven directions were also examined similarly and the results are summarised in Table 4.3.1.2.5.

Table 4.3.1.2.5: Comparison between the running average of four runs to that of six runs in all eight directions.

Direction	Mean Peak Velocity (Deg/sec)	AVG of 10runs		AVG of 4 runs		AVG of 6runs	
		Mean error	Stdev error	Mean error	Stdev error	Mean error	Stdev error
TEM	402	0	0	9	15	4	10
NAS	318	0	0	3	12	2	10
UP	272	0	0	1	14	1	8
DOWN	286	0	0	5	18	3	11
UN	289	0	0	6	14	4	10
DT	317	0	0	11	30	5	19
UT	345	0	0	5	18	7	8
DN	299	0	0	7	17	4	14
			Average all directions	**6**	**17**	**4**	**11**

4.3.1.3 Amplitude:

The group mean of amplitudes obtained from the 20 young observers for the 10 runs in all the eight directions is shown in Figure 4.3.1.3.1.Each point on the graph represent the group mean arising from all the observers in each run respectively. The error bars also show the standard deviations.

An ANOVA was applied in each direction separately and the results revealed that all directions showed no significant difference ($p>0.05$) within the group between any of the ten runs (Table 4.3.1.3.1).

The mean and the standard deviations in each direction shown in Figure 4.3.1.3.1 are summarised in Table 4.3.1.3.2.

Table 4.3.1.3.1: Repeated measurements ANOVA results for the individual runs.

Directions	**ANOVA results** (Individual runs)
TEM	F (9,153) = 0.86, p = 0.57
NAS	F (9,153) = 0.77, p = 0.64
UP	F (9,135) = 1.06, p = 0.40
DOWN	F (9,117) = 1.79, p = 0.80
UN	F (9.117) = 1.66, p = 0.11
DT	F (9,135) = 0.95, p = 0.49
UT	F (9,126) = 1.41, p = 0.19
DN	F (9,135) = 0.62, p = 0.77

Table 4.3.1.3.2: Group mean amplitudes, standard deviations and coefficient of variation for all individual 10 runs and 20 observers in each direction separately.

Directions	*Mean Amplitude (Degrees) (Group mean)*	*Stdev*	*Coefficient of variation %*
TEM	**9.86**	**± 2.49**	**25**
NAS	**9.33**	**± 1.74**	**19**
UP	**8.69**	**± 1.59**	**18**
DOWN	**8.47**	**± 1.61**	**19**
UN	**10.76**	**± 2.83**	**26**
DT	**8.49**	**± 1.57**	**18**
UT	**10.17**	**± 1.22**	**12**
DN	**8.22**	**± 1.67**	**20**
AVERAGE FOR ALL DIRECTIONS	**9.25**	**± 1.84**	**20 %**

The mean amplitudes illustrated in Figure 4.3.1.3.1 show no statistically significant change across the ten runs for all the directions separately. There is no evidence of a trend towards an increase or decrease.

Figure 4.3.1.3.2 represents the running averages. A visual inspection of Figure 4.3.1.3.2 reveals little difference between the single and the tenth running averages result. A repeated measurement ANOVA revealed a non-significant difference across the running averages in all directions (Table 4.3.1.3.3).

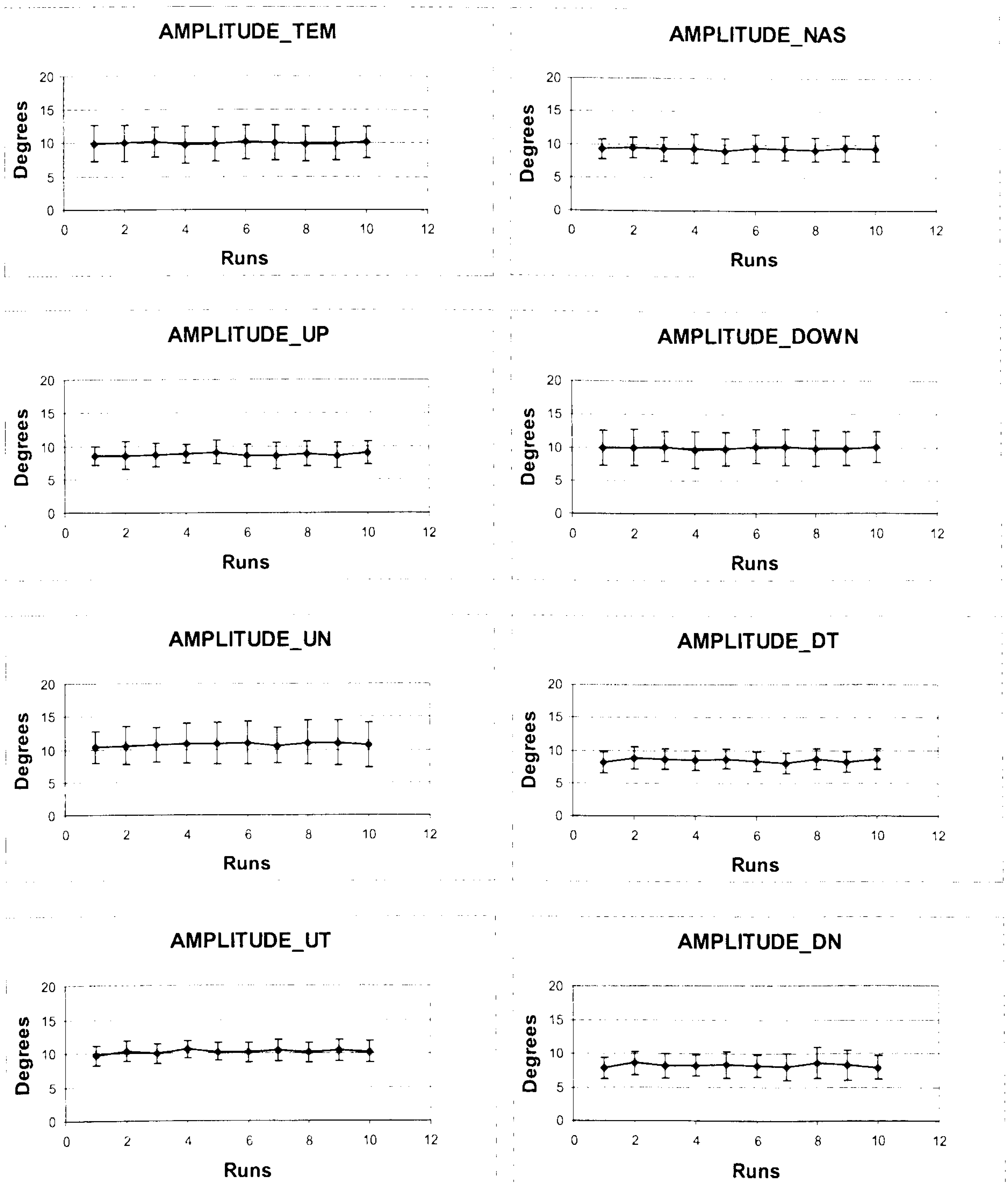


Figure 4.3.1.3.1: Each point on the graph represents the group mean obtain from the twenty individual subject measurements for amplitude. The error bars show the standard deviation for each run.

Table 4.3.1.3.3: Repeated measurements ANOVA results for the running averages.

Directions	ANOVA results (Running averages)
TEM	F (9,171) = 0.44, p = 0.91
NAS	F (9,171) = 0.50, p = 0.87
UP	F (9,153) = 1.12, p = 0.35
DOWN	F (9,153) = 0.67, p = 0.73
UN	F (9,171) = 1.66, p = 0.10
DT	F (9,162) = 0.74, p = 0.67
UT	F (9,171) = 4.85, p = 0.07
DN	F (9,162) = 0.99, p = 0.45

Figure 4.3.1.3.2 and the results obtained from the ANOVA suggest that a representative value of amplitude might be achieved even from a single run. Table 4.3.1.3.4 shows the running average amplitude error for the up direction of each observer expressed as the amplitude error compared to the tenth one.

Table 4.3.1.3.4: The running average amplitude for the vertical up direction of each subject expressed as the amplitude error compared with the tenth run. Negative values indicate smaller amplitude whereas positive values indicate larger amplitudes.

UP	ERRORS		AMPLITUDE (Degrees)							
Sxs	1	1+2	1+2+3	1+..+4	1+..+5	1+..+6	1+..+7	1+..+8	1+..+9	1+..+10
AS	/////////////	0.70	0.55	0.21	0.14	0.31	0.23	0.22	0.07	0.00
AR	-1.93	-0.36	-0.47	-0.44	-0.53	-0.49	-0.41	-0.38	-0.26	0.00
AB	0.01	0.12	-0.09	0.01	0.17	0.17	0.12	0.05	-0.06	0.00
AN	0.33	0.19	0.15	0.01	0.26	0.18	0.04	0.06	0.04	0.00
AM	/////////////	-0.38	-0.21	-0.24	-0.21	-0.33	-0.39	-0.29	-0.17	0.00
CH	0.09	-1.11	-0.65	-0.25	0.09	0.09	0.05	0.00	-0.02	0.00
DC	0.68	0.62	0.37	0.30	0.39	0.31	0.27	0.13	0.00	0.00
EP	-0.86	-1.30	-1.12	-0.69	-0.55	-0.40	-0.39	-0.26	-0.14	0.00
EL	0.64	0.67	0.78	0.71	0.47	0.21	0.18	0.04	-0.01	0.00
EG	-1.41	-0.63	-0.45	-0.26	-0.11	-0.02	-0.03	0.00	-0.01	0.00
IM	1.13	0.59	0.64	0.46	0.33	0.20	0.13	0.08	-0.02	0.00
IU	-0.65	0.24	0.41	0.39	0.38	0.15	0.18	0.11	0.06	0.00
KH	-2.14	-1.30	-1.20	-0.89	-0.63	-0.54	-0.30	-0.30	-0.05	0.00
MB	1.16	0.19	-0.19	-0.07	0.01	0.03	0.02	0.11	0.07	0.00
MM	-0.66	-0.52	-0.62	-0.52	-0.16	-0.08	0.00	0.38	0.17	0.00
PM	1.00	-0.46	-0.65	0.05	0.19	0.08	-0.09	-0.05	-0.14	0.00
PK	0.10	0.26	0.40	0.28	0.33	0.26	0.12	0.09	0.03	0.00
RS	0.26	0.17	0.01	-0.21	-0.25	-0.37	-0.27	-0.10	0.00	0.00
SN	-0.60	-0.17	0.01	0.04	0.02	-0.03	0.00	0.00	0.03	0.00
VA	-1.47	-0.66	-0.21	-0.09	-0.04	-0.05	-0.18	-0.22	-0.11	0.00
average	-0.24	-0.16	-0.13	-0.06	0.02	-0.02	-0.04	-0.02	-0.03	0.00
stdev	1.03	0.63	0.56	0.40	0.33	0.27	0.22	0.19	0.10	0.00

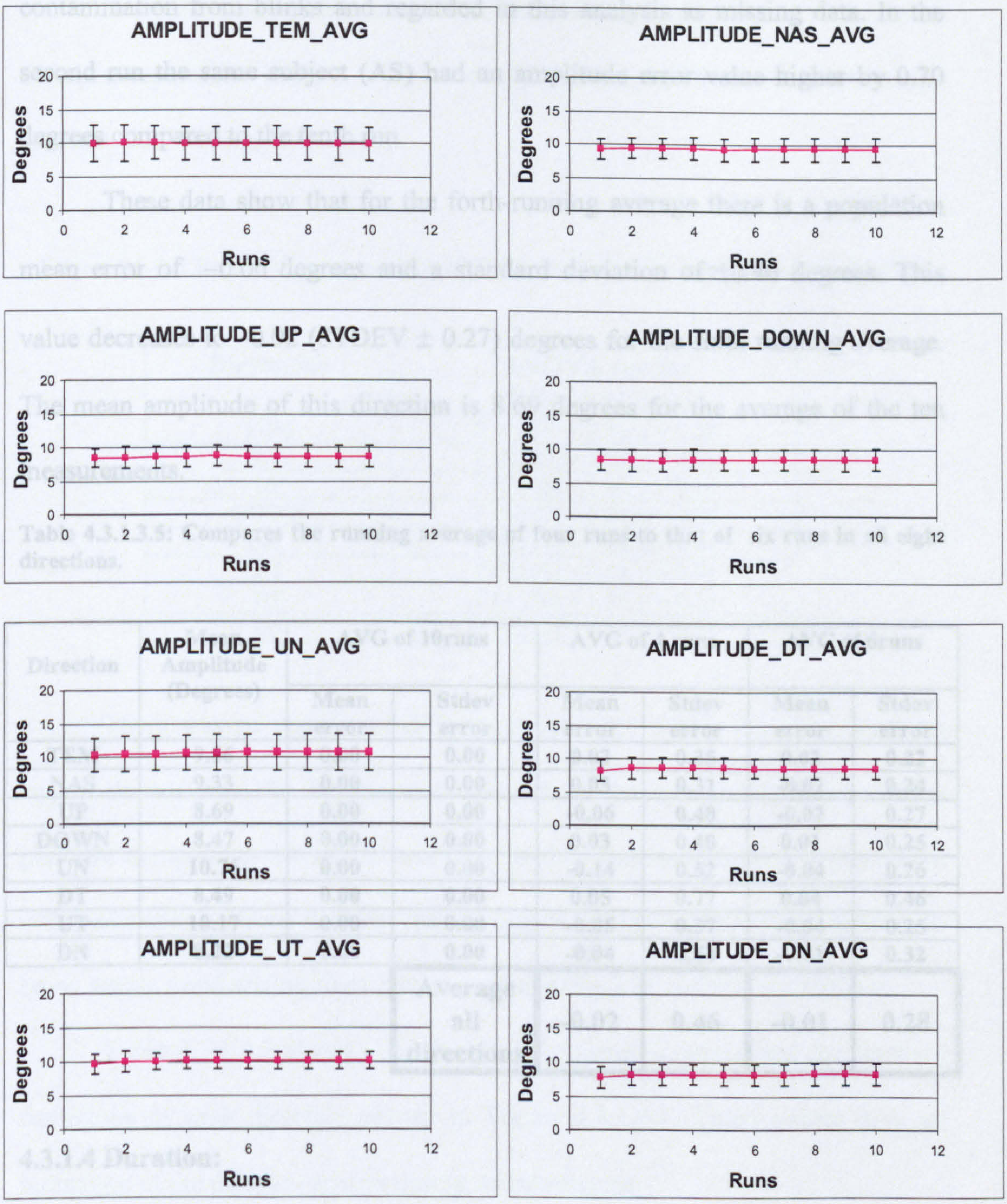


Figure 4.3.1.3.2: Running averages for amplitude. Each point on these graphs are the group mean obtaining from the twenty individual measurements for amplitude. Run number one is the group mean arising from 20 data values, run number two is the average of 40 and run number ten is the average of 200 data values. The error bars show the standard deviation for each run.

Table 4.3.1.3.4 shows that the first run of our first subject (AS) was disregarded either due to the effect of anticipation (negative latencies) and/or contamination from blinks and regarded in this analysis as missing data. In the second run the same subject (AS) had an amplitude error value higher by 0.70 degrees compared to the tenth run.

These data show that for the forth-running average there is a population mean error of –0.06 degrees and a standard deviation of ±0.40 degrees. This value decreases to –0.02 (STDEV ± 0.27) degrees for the sixth running average. The mean amplitude of this direction is 8.69 degrees for the average of the ten measurements.

Table 4.3.1.3.5: Compares the running average of four runs to that of six runs in all eight directions.

Direction	Mean Amplitude (Degrees)	AVG of 10runs		AVG of 4 runs		AVG of 6runs	
		Mean error	Stdev error	Mean error	Stdev error	Mean error	Stdev error
TEM	9.86	0.00	0.00	0.03	0.35	0.02	0.22
NAS	9.33	0.00	0.00	0.03	0.31	-0.01	0.24
UP	8.69	0.00	0.00	-0.06	0.40	-0.02	0.27
DOWN	8.47	0.00	0.00	0.03	0.40	0.01	0.25
UN	10.76	0.00	0.00	-0.14	0.52	-0.04	0.26
DT	8.49	0.00	0.00	0.05	0.77	0.04	0.46
UT	10.17	0.00	0.00	-0.05	0.37	-0.04	0.25
DN	8.22	0.00	0.00	-0.04	0.54	-0.01	0.32
			Average all directions	**-0.02**	**0.46**	**-0.01**	**0.28**

4.3.1.4 Duration:

Figure 4.3.1.4.1 shows the group mean duration obtained for the 20 subjects in the young age group for the ten individual runs in all directions. A visual inspection of Figure 4.3.1.4.1 reveals that duration values in this age group are relatively stable with a small variation among the observers.

A repeated measurements ANOVA was applied in this set of data in each direction separately. Table 4.3.1.4.1 shows a summary of those ANOVA results for each direction respectively.

Table 4.3.1.4.1: Repeated measurements ANOVA results for the individual runs obtained.

Directions	**ANOVA results** (Individual runs)
TEM	F (9,153) = 1.34, p = 0.22
NAS	F (9,153) = 1.76, p = 0.08
UP	F (9,135) = 1.49, p = 0.16
DOWN	F (9,117) = 1.20, p = 0.30
* **UN**	**F (9,117) = 2.04, p = 0.04**
DT	F (9,135) = 0.44, p = 0.91
UT	F (9,126) = 1.35, p = 0.22
DN	F (9,135) = 1.29, p = 0.25

There was no significant difference (p>0.05) within the group between any of the ten runs for all directions apart from the up nasal (UN). A further pairwise comparison across the ten runs in this direction showed a significant difference only between the first and the eighth run (p = 0.03). There appears to be no within trend arising from factors such as fatigue or changes in attention

Table 4.3.1.4.2 shows a summary of the mean durations and the standard deviations in each direction shown in Figure 4.3.1.4.1. These values give an indication of the duration arising during measurements.

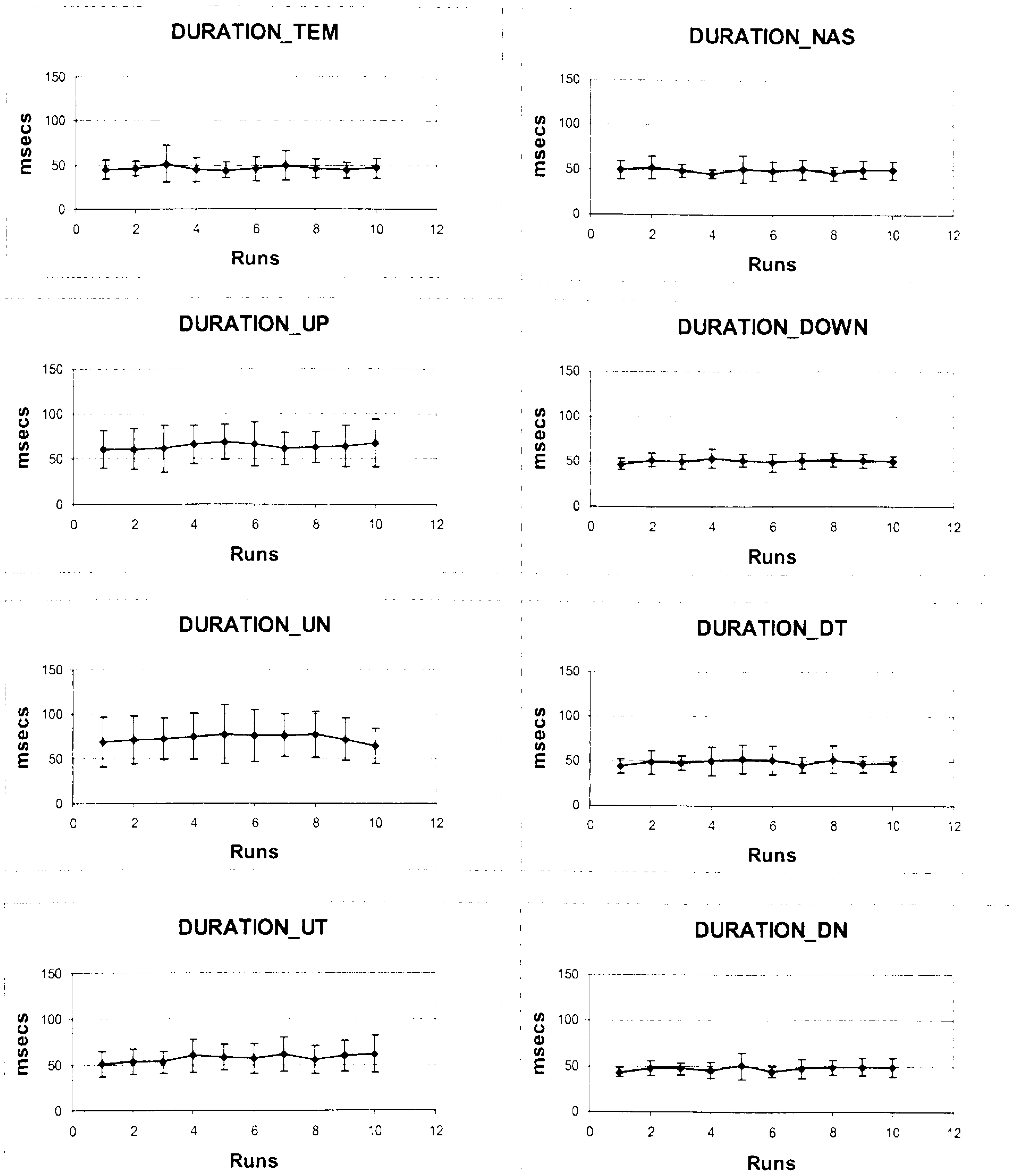


Figure 4.3.1.4.1: Each point on the graph represents the group mean obtain from the twenty individual subject measurements for duration. The error bars show the standard deviations for each run.

Table 4.3.1.4.2: Group mean durations, standard deviations and coefficient of variation for all individual 10 runs and 20 observers in each direction separately.

Directions	*Mean Duration (Seconds) (Group mean)*	*Stdev*	*Coefficient of variation %*
TEM	**47**	**±12**	**25**
NAS	**49**	**± 7**	**15**
UP	**64**	**±19**	**30**
DOWN	**51**	**± 4**	**9**
UN	**74**	**±25**	**34**
DT	**49**	**± 9**	**19**
UT	**57**	**±13**	**23**
DN	**47**	**± 6**	**12**
AVERAGE FOR ALL DIRECTIONS	**55**	**± 12**	**21 %**

Figure 4.3.1.4.2 represents the running averages. A visual inspection of Figure 4.3.1.4.2 reveals a stable duration even from the first run in some directions.

A repeated measurement ANOVA revealed a non-significant difference across the averaged ten runs in all directions except two (UT, DN) (Table 4.3.1.4.3). Table 4.3.1.4.3 shows a summary of the ANOVA results obtained from the running averages for each direction respectively.

Table 4.3.1.4.3: Repeated measurements ANOVA results for the running averages.

Directions	**ANOVA results** (Running averages)
TEM	$F\,(9,171) = 2.13,\ p = 0.40$
NAS	$F\,(9,171) = 1.19,\ p = 0.30$
UP	$F\,(9,153) = 1.59,\ p = 0.12$
DOWN	$F\,(9,153) = 2.20,\ p = 0.19$
UN	$F\,(9,171) = 5.07,\ p = 0.26$
DT	$F\,(9,162) = 3.98,\ p = 0.76$
* **UT**	$\mathbf{F\,(9,171) = 5.35,\ p < 0.001}$
* **DN**	$\mathbf{F\,(9,162) = 4.86,\ p < 0.001}$

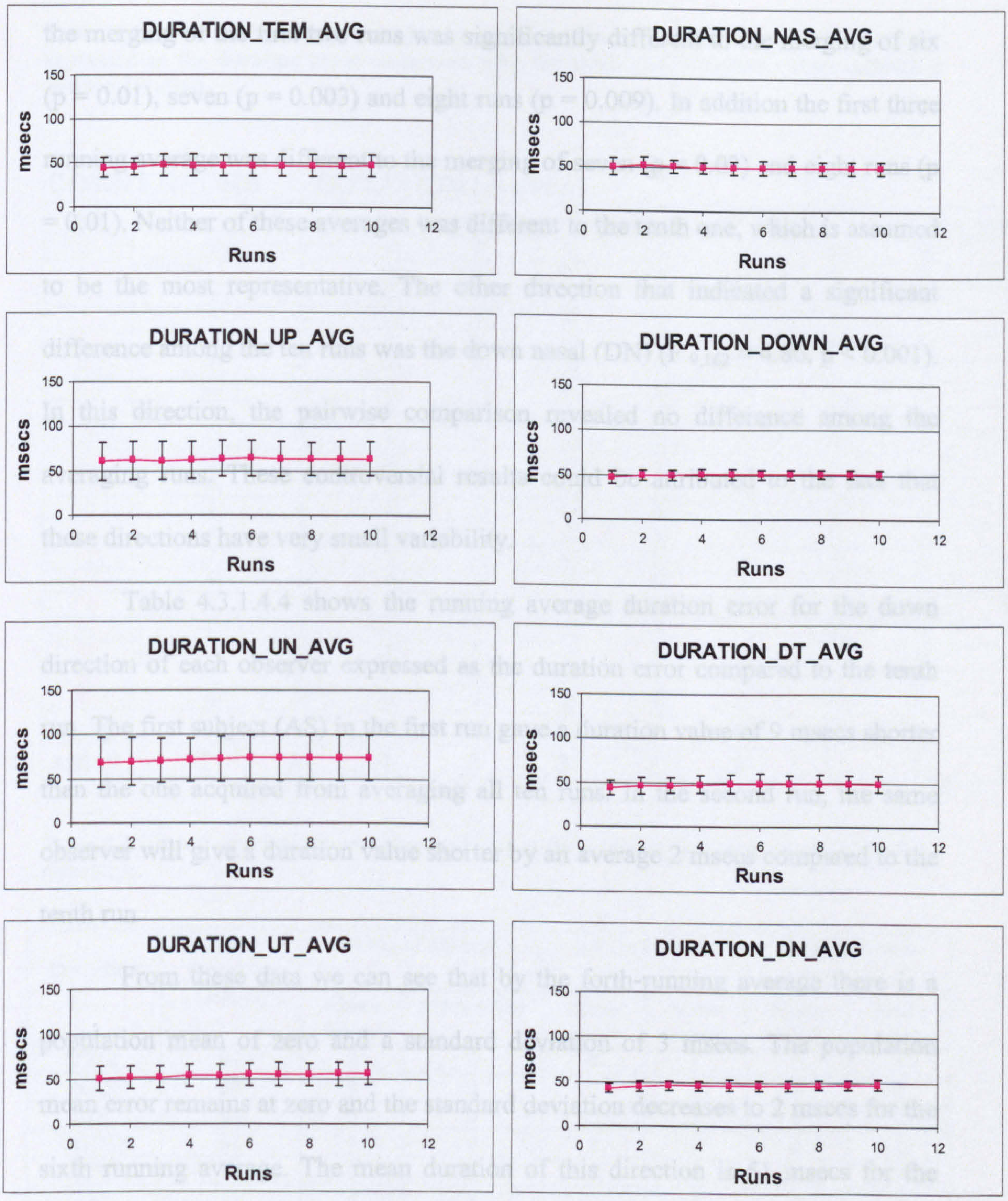


Figure 4.3.1.4.2: Running averages of duration. Each point on these graphs are the group mean obtaining from the twenty individual measurements for duration. Run number one is the group mean arising from 20 data values, run number two is the average of 40 and run number ten is the average of 200 data values. The error bars show the standard deviation for each run.

In the case of the UT direction, there is a significant difference across the averaged ten runs ($F_{9,171} = 5.35$, $p < 0.001$). A pairwise comparison revealed that the merging of the first two runs was significantly different to the merging of six ($p = 0.01$), seven ($p = 0.003$) and eight runs ($p = 0.009$). In addition the first three running average was different to the merging of seven ($p = 0.03$) and eight runs ($p = 0.01$). Neither of these averages was different to the tenth one, which is assumed to be the most representative. The other direction that indicated a significant difference among the ten runs was the down nasal (DN) ($F_{9,162} = 4.86$, $p < 0.001$). In this direction, the pairwise comparison revealed no difference among the averaging runs. These controversial results could be attributed to the fact that these directions have very small variability.

Table 4.3.1.4.4 shows the running average duration error for the down direction of each observer expressed as the duration error compared to the tenth run. The first subject (AS) in the first run gave a duration value of 9 msecs shorter than the one acquired from averaging all ten runs. In the second run, the same observer will give a duration value shorter by an average 2 msecs compared to the tenth run.

From these data we can see that by the forth-running average there is a population mean of zero and a standard deviation of 3 msecs. The population mean error remains at zero and the standard deviation decreases to 2 msecs for the sixth running average. The mean duration of this direction is 51 msecs for the average of ten measurements.

Table 4.3.1.4.4: The running average duration for the down direction of each subject expressed as the duration error compared with the tenth run. Negative values indicate a shorter duration.

DOWN	ERRORS		DURATION (msecs)							
Sxs	**1**	**1+2**	**1+2+3**	**1+..+4**	**1+..+5**	**1+..+6**	**1+..+7**	**1+..+8**	**1+..+9**	**1+..+10**
AS	-9	-2	-2	0	0	0	0	-1	0	0
AR	////////////	1	-1	-2	-3	-2	-1	0	0	0
AB	-4	-1	0	-1	1	0	0	0	0	0
AN	-5	0	4	4	4	1	1	1	1	0
AM	-1	1	-1	-3	-4	-4	-4	-3	0	0
CH	-7	-2	-4	0	0	2	2	1	1	0
DC	-13	-8	-8	-7	-5	-6	-3	-1	-1	0
EP	12	4	0	2	3	1	1	1	0	0
EL	-2	-2	-2	4	3	2	2	2	1	0
EG	-1	3	3	6	6	1	1	1	1	0
IM	-13	-10	-8	-3	-3	-1	-1	1	0	0
IU	13	6	3	2	0	0	1	2	1	0
KH	-4	-2	-3	-3	-2	-3	-1	-1	-1	0
MB	-7	2	1	4	4	3	1	0	0	0
MM	-5	-3	0	0	0	0	0	0	0	0
PM	-2	-2	-1	0	1	2	1	1	0	0
PK	-9	-1	-1	1	-1	-1	-1	0	0	0
RS	////////////	-3	7	4	2	1	1	0	0	0
SN	-7	-2	-2	-2	-2	1	0	1	0	0
VA	-5	-5	-3	-2	-3	-2	-3	-1	-1	0
avg	**-4**	**-1**	**-1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
stdev	**7**	**4**	**4**	**3**	**3**	**2**	**2**	**1**	**1**	**0**

Table 4.3.1.4.5: Compares the running averages of four runs to that of six runs in all eight directions.

Direction	Mean Duration (msecs)	AVG of 10runs		AVG of 4 runs		AVG of 6runs	
		Mean error	Stdev error	Mean error	Stdev error	Mean error	Stdev error
TEM	47	0	0	0	3	-1	1
NAS	49	0	0	0	2	0	2
UP	64	0	0	-1	3	0	2
DOWN	51	0	0	0	3	0	2
UN	74	0	0	-2	4	-1	3
DT	49	0	0	-1	4	0	3
UT	57	0	0	-3	3	-2	2
DN	47	0	0	-1	3	-1	2
			Average all directions	**-1**	**3**	**-1**	**2**

4.3.2 Group II (40-59 years)

The same methodology was followed for the second age group for each saccadic parameter and each direction respectively.

4.3.2.1 Latency:

Figure 4.3.2.1.1 represents the group mean latencies obtained for the 20 subjects in the middle-aged group for the 10 runs in all directions. Each point on the graph is the group mean arising from the twenty individual subject values for each run. The error bars show the standard deviation, which represents the intersubject variability within each run. Table 4.3.2.1.1 shows a summary of those ANOVA results for each direction respectively.

Table 4.3.2.1.1: Repeated measurements ANOVA results for the individual runs.

Directions	ANOVA results (Individual runs)
* **TEM**	**F (9,144) = 4.52, p < 0.001**
* **NAS**	**F (9,126) = 4.33, p < 0.001**
* **UP**	**F (9,99) = 5.37, p < 0.001**
DOWN	F (9,108) = 0.83, p = 0.59
* **UN**	**F (9,126) = 4.34, p = 0.001**
* **DT**	**F (9,108) = 2.18, p = 0.03**
* **UT**	**F (9,126) = 5.61, p < 0.001**
DN	F (9,90) = 1.67, p = 0.11

The majority of directions showed a significant difference ($p<0.05$) within the group between any of the ten runs. A pairwise comparison revealed that in the temporal direction, there was a significant difference between the first and the third, sixth and seventh individual run. In the nasal direction, this difference was between the first run and that of the third, forth and fifth one. Whereas in the up direction, the saccadic latency of the first run was different from the one in the third and the eighth individual run. This result may indicate an attentional or learning effect since in all these directions the differences occur at the level of the first run.

In three oblique directions (UN, DT, UT) the results obtained from the ANOVA were controversial. The within-subjects test revealed a significantly different effect between the ten runs but the pairwise comparisons between the ten runs revealed no such difference.

From the above data, there appears to be some variation in the results but the graphs in Figure 4.3.2.1.1 show no obvious trend towards an increase or decrease with successive measurement apart from an initial high value of the first measurement in some of the directions.

The standard deviations indicate the overall intersubject variability. The mean and the standard deviations in each direction shown in Figure 4.3.2.1.1 are summarised in Table 4.3.2.1.2.

Table 4.3.2.1.2: Mean latencies, standard deviations and coefficient of variation for all individual 10 runs and 20 observers in each direction separately.

Directions	*Mean Latency (msecs) (Group mean)*	*Stdev*	*Coefficient of variation %*
TEM	248	± 34	12
NAS	253	± 27	12
UP	251	± 30	12
DOWN	267	±32	11
UN	251	±23	9
DT	256	±32	12
UT	254	± 30	12
DN	263	±29	12
AVERAGE FOR ALL DIRECTIONS	**255**	**±30**	**12 %**

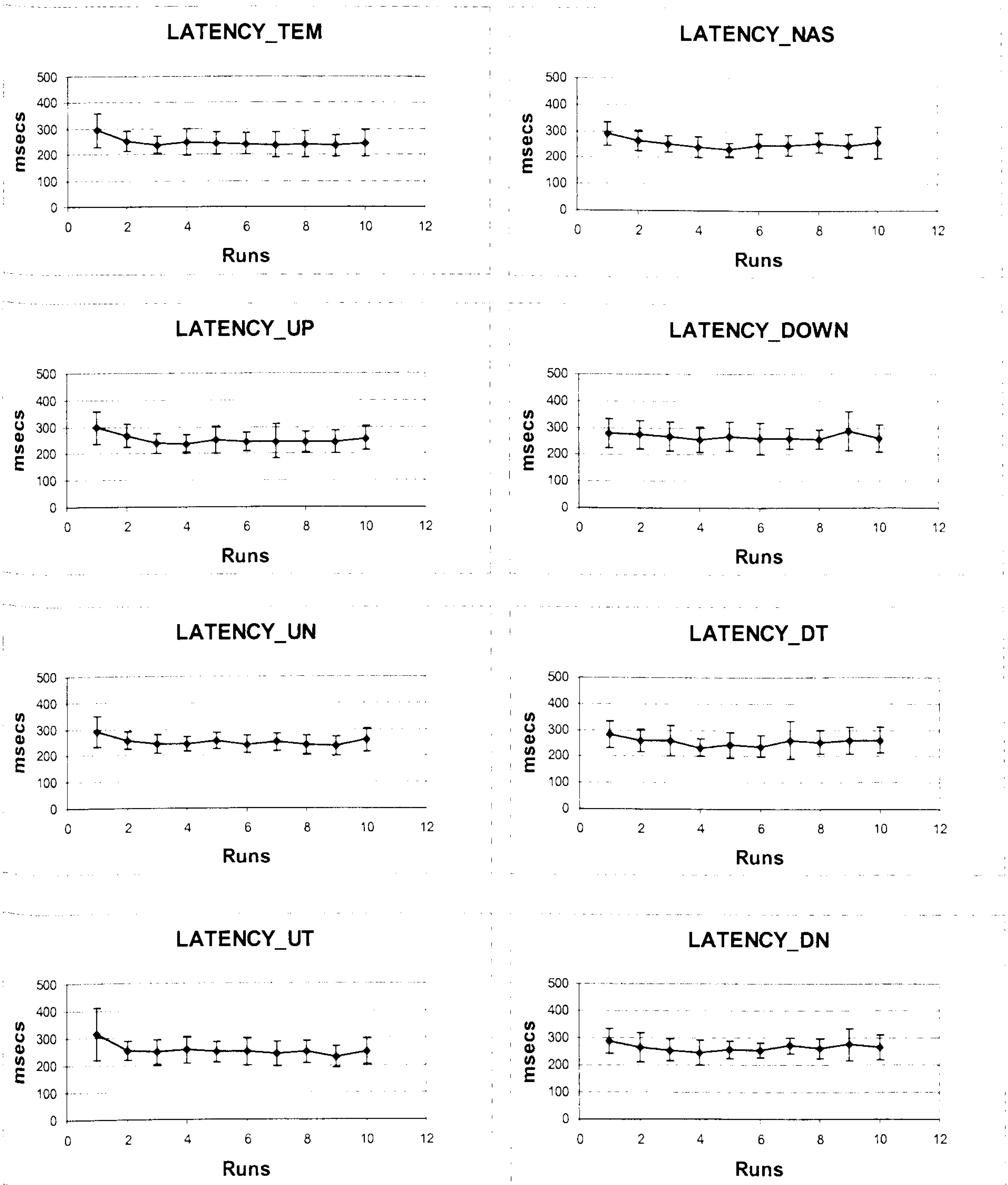


Figure 4.3.2.1.1: Each point on the graph represents the group mean obtain from the twenty individual subject measurements for latency. The error bars show the standard deviations for each run.

Figure 4.3.2.1.2 represents the running averages. A visual inspection of Figure 4.3.2.1.2 reveals an early progressive reduction in latency as more runs are averaged after which the latency value appears stable. This progressive reduction in mean latency and its standard deviation might be due to the increasingly effective elimination of noise.

An ANOVA revealed a non-significant difference across the running averages in most of the directions (Table 4.3.2.1.3).

Table 4.3.2.1.3: Repeated measurements ANOVA results for the running averages.

Directions	**ANOVA results** (Running averages)
* **TEM**	**$F_{(9,171)} = 15.67$, $p < 0.001$**
* **NAS**	**$F_{(9,162)} = 14.29$, $p < 0.001$**
* **UP**	**$F_{(9,162)} = 16.53$, $p < 0.001$**
DOWN	$F_{(9,153)} = 1.03$, $p = 0.42$
UN	$F_{(9.153)} = 9.66$, $p = 0.14$
DT	$F_{(9,153)} = 6.37$, $p = 0.11$
UT	$F_{(9,162)} = 7.72$, $p = 0.46$
DN	$F_{(9,153)} = 7.46$, $p = 0.31$

In the cases of temporal (TEM) and up (UP) directions, there are significant differences (TEM: $F_{9,171} = 14.67$, $p < 0.001$; UP: $F_{9,162} = 16.53$, $p<0.001$). A pairwise comparison revealed that the first two running averages are significantly different from the remaining ones in both directions respectively. The other direction that also indicated a significant difference among the ten runs was the nasal direction (NAS) ($F_{9,162} = 14.29$, $p<0.001$). In this direction, the first three averages were significantly different from the remaining ones. Thus ANOVA suggests that the running averages of latency in the middle-aged group are representative after the merging of three for the temporal and upward direction and four runs for the nasal direction

Table 4.3.2.1.4 shows the running average latencies error for the oblique up-nasal (UN) direction of each observer expressed as the latency error compared to the tenth run. For subject one (AP) the first run will give a latency value of 41 msecs longer than the one acquired from averaging all ten runs and the second run will give a value longer by 19 msecs compared to the tenth run.

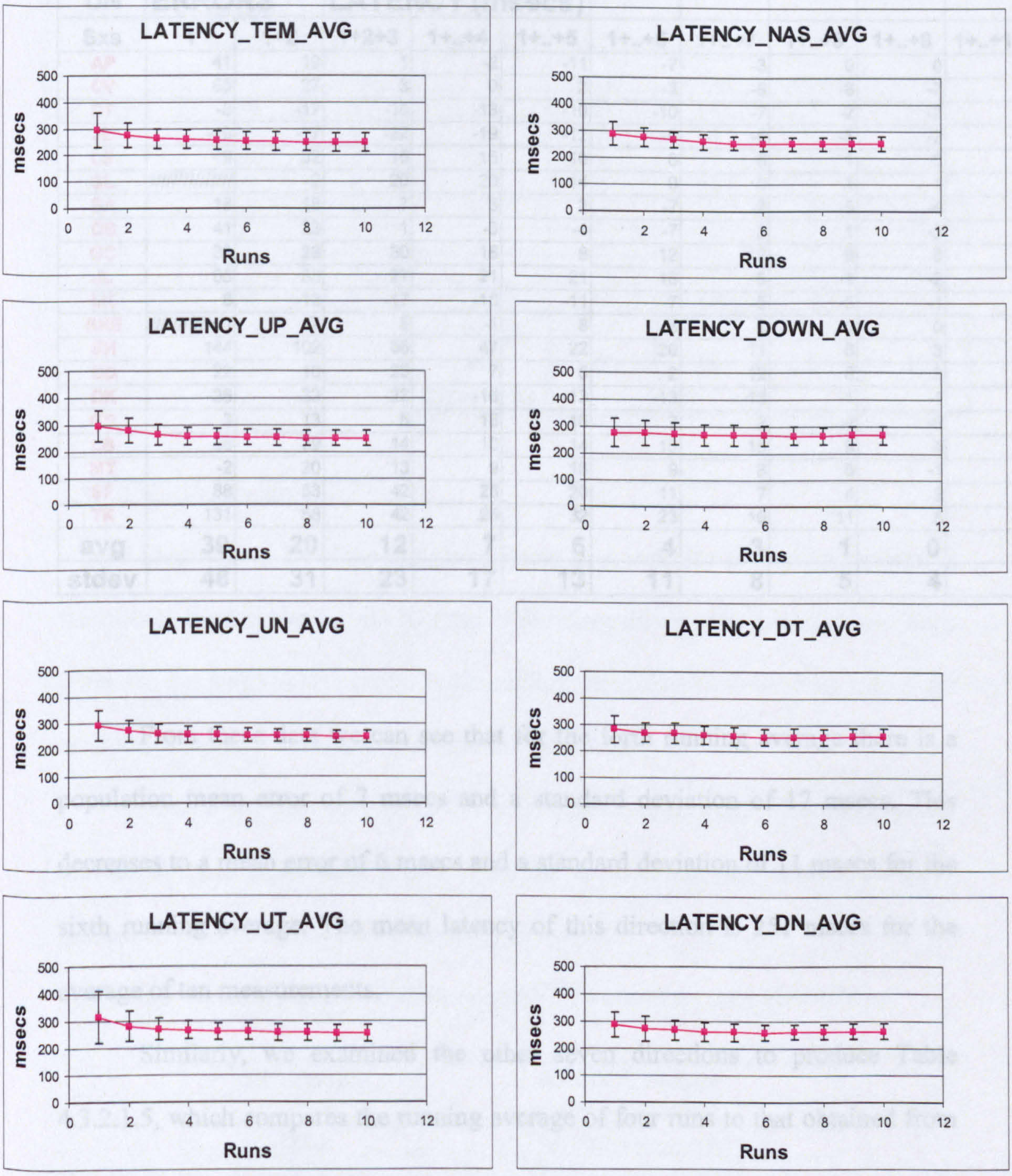


Figure 4.3.2.1.2: Running averages of latency in group II (range 40-59 years). Each point on these graphs are the group mean obtaining from the twenty individual measurements for latency. Run number one is the group mean arising from 20 data values, run number two is the average of 40 and run number ten is the average of 200 data values. The error bars show ±1 STDEV for each run.

Table 4.3.2.1.4: The running average latencies for the oblique up-nasal (UN) direction of each subject expressed as the latency error compared with the tenth run. Negative values indicate a shorter latency.

UN	ERRORS		LATENCY (msecs)							
Sxs	**1**	**1+2**	**1+2+3**	**1+..+4**	**1+..+5**	**1+..+6**	**1+..+7**	**1+..+8**	**1+..+9**	**1+..+10**
AP	41	19	1	-2	-11	-7	-3	0	0	0
CV	65	27	3	0	2	-3	-6	-8	-7	0
DT	-8	-17	-16	-13	-10	-10	-7	-2	-2	0
JB	-19	-17	-22	-19	-12	-9	-6	-5	-2	0
LS	49	32	15	15	10	6	6	1	0	0
SL	//////////////	-2	20	20	14	9	0	1	1	0
SA	18	18	7	3	2	-7	-2	-5	-4	0
DB	41	23	1	-3	-4	-7	3	1	-3	0
GC	33	28	30	16	8	12	12	9	6	0
JL	65	38	27	21	21	16	5	-1	-2	0
LK	8	-12	-17	-16	-11	-7	-5	-5	-1	0
SHE	//////////////	7	5	-1	8	3	1	0	0	0
SH	144	102	66	47	22	20	11	6	3	0
BD	22	10	25	7	5	2	12	8	3	0
DK	-36	-33	-23	-16	-13	-13	-13	-1	-1	0
GB	3	13	5	16	16	7	2	-4	-9	0
LB	56	39	14	10	14	15	15	9	4	0
MT	-2	20	13	9	16	9	8	5	-1	0
SF	88	53	42	25	20	11	7	4	2	0
TK	131	58	42	25	32	23	16	11	5	0
avg	**39**	**20**	**12**	**7**	**6**	**4**	**3**	**1**	**0**	**0**
stdev	**48**	**31**	**23**	**17**	**13**	**11**	**8**	**5**	**4**	**0**

From these data we can see that for the forth running average there is a population mean error of 7 msecs and a standard deviation of 17 msecs. This decreases to a mean error of 6 msecs and a standard deviation of 11 msecs for the sixth running average. The mean latency of this direction is 251 msecs for the average of ten measurements.

Similarly, we examined the other seven directions to produce Table 4.3.2.1.5, which compares the running average of four runs to that obtained from six runs.

Table 4.3.2.1.5: Comparison between the running average of four runs to that of six runs.

Direction	Mean latency (msecs)	AVG of 10runs		AVG of 4 runs		AVG of 6runs	
		Mean error	Stdev error	Mean error	Stdev error	Mean error	Stdev error
TEM	248	0	0	11	14	5	10
NAS	253	0	0	8	18	0	15
UP	251	0	0	8	17	4	12
DOWN	267	0	0	2	22	0	15
UN	251	0	0	7	17	4	11
DT	256	0	0	6	21	-2	12
UT	254	0	0	12	19	6	11
DN	263	0	0	-1	13	-4	9
			Average all directions	**7**	**18**	**2**	**12**

4.3.2.2 Peak velocity

Figure 4.3.2.2.1 show the group mean peak velocity for the 20 subjects in the middle-aged group for all 10 runs in the directions under investigation. Each point on the graph is the group mean arising from the 20 individual values for each run. The error bars show the standard deviation.

A repeated measures ANOVA was applied in all eight directions for the individual runs separately. Table 4.3.2.2.1 summarizes the results of those individual runs ANOVA results for each direction.

Table 4.3.2.2.1: Repeated measurements ANOVA results for the individual runs.

Directions	ANOVA results (Individual runs)
TEM	$F(9,144) = 1.44, p = 0.18$
NAS	$F(9,126) = 0.69, p = 0.72$
UP	$F(9,99) = 0.93, p = 0.50$
DOWN	$F(9,108) = 1.10, p = 0.37$
UN	$F(9.126) = 1.73, p = 0.09$
DT	$F(9,108) = 0.72, p = 0.69$
UT	$F(9,126) = 0.79, p = 0.63$
DN	$F(9,90) = 1.60, p = 0.13$

All directions showed no significant difference ($p>0.05$) within the group between any of the ten runs. There appears to be no within trend arising from factors such as fatigue or changes in attention. The standard deviations indicate the overall intersubject variability. The mean and the standard deviations in each direction shown in Figure 4.3.2.2.1 are summarised in Table 4.3.2.2.2. These values give an indication of the peak velocity variation arising during measurements.

Table 4.3.2.2.2: Group mean peak velocities, standard deviations and coefficient of variation for all individual 10 runs and 20 observers in each direction separately.

Directions	*Mean Peak Velocity (Deg/sec) (Group mean)*	*Stdev*	*Coefficient of variation %*
TEM	466	± 113	24
NAS	335	± 89	27
UP	268	± 50	19
DOWN	280	± 67	24
UN	315	± 94	30
DT	301	± 92	31
UT	417	± 163	39
DN	266	± 79	30
AVERAGE FOR ALL DIRECTIONS	**331**	**± 93**	**28 %**

Figure 4.3.2.2.2 represents the running averages. An ANOVA also revealed a non-significant difference across the averaged ten runs in all the directions under investigation except one (DN) (Table 4.3.1.2.3).

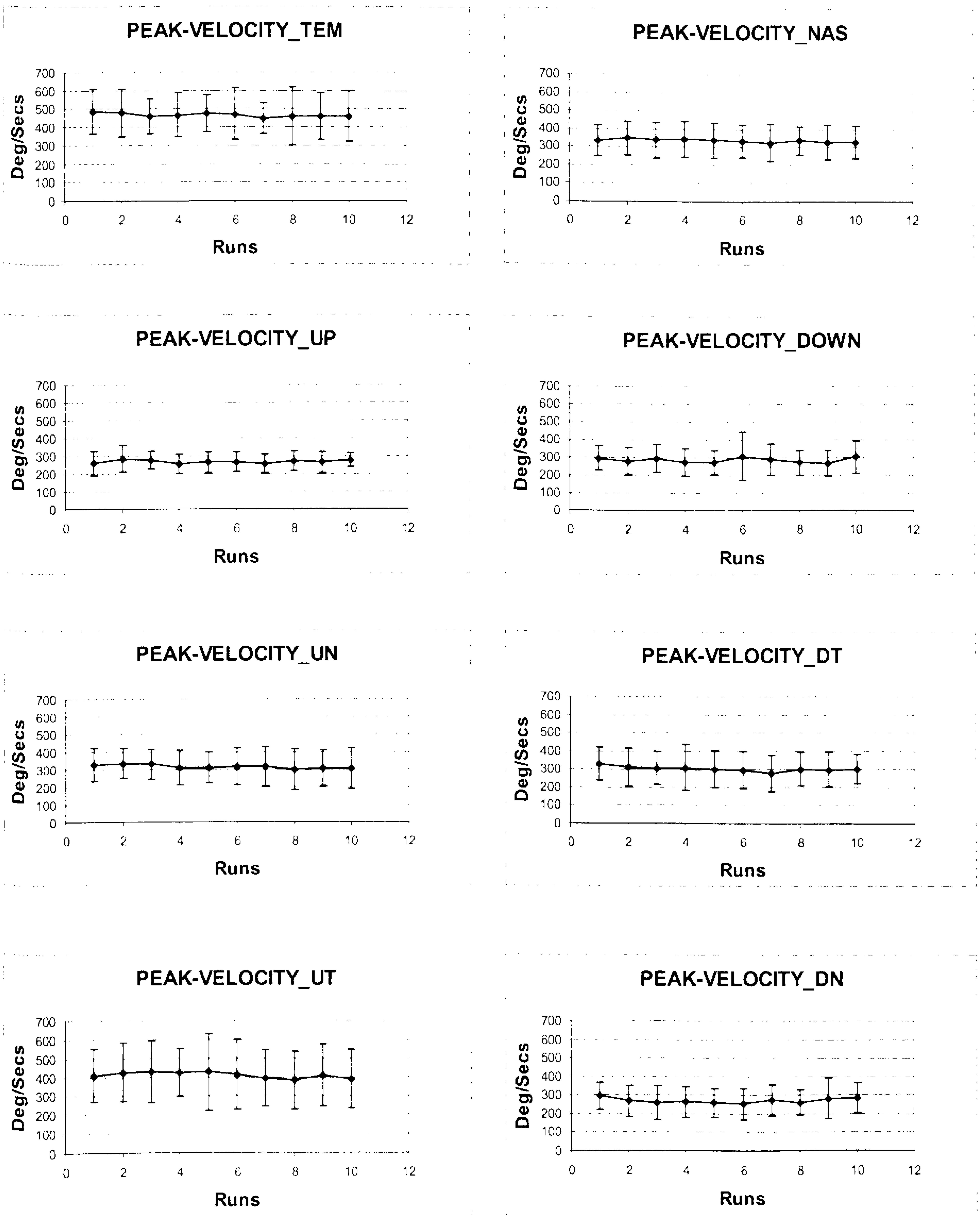


Figure 4.3.2.2.1: Each point on the graph represents the group mean obtain from the twenty individual subject measurements for peak velocity. The error bars show the standard deviations for each run.

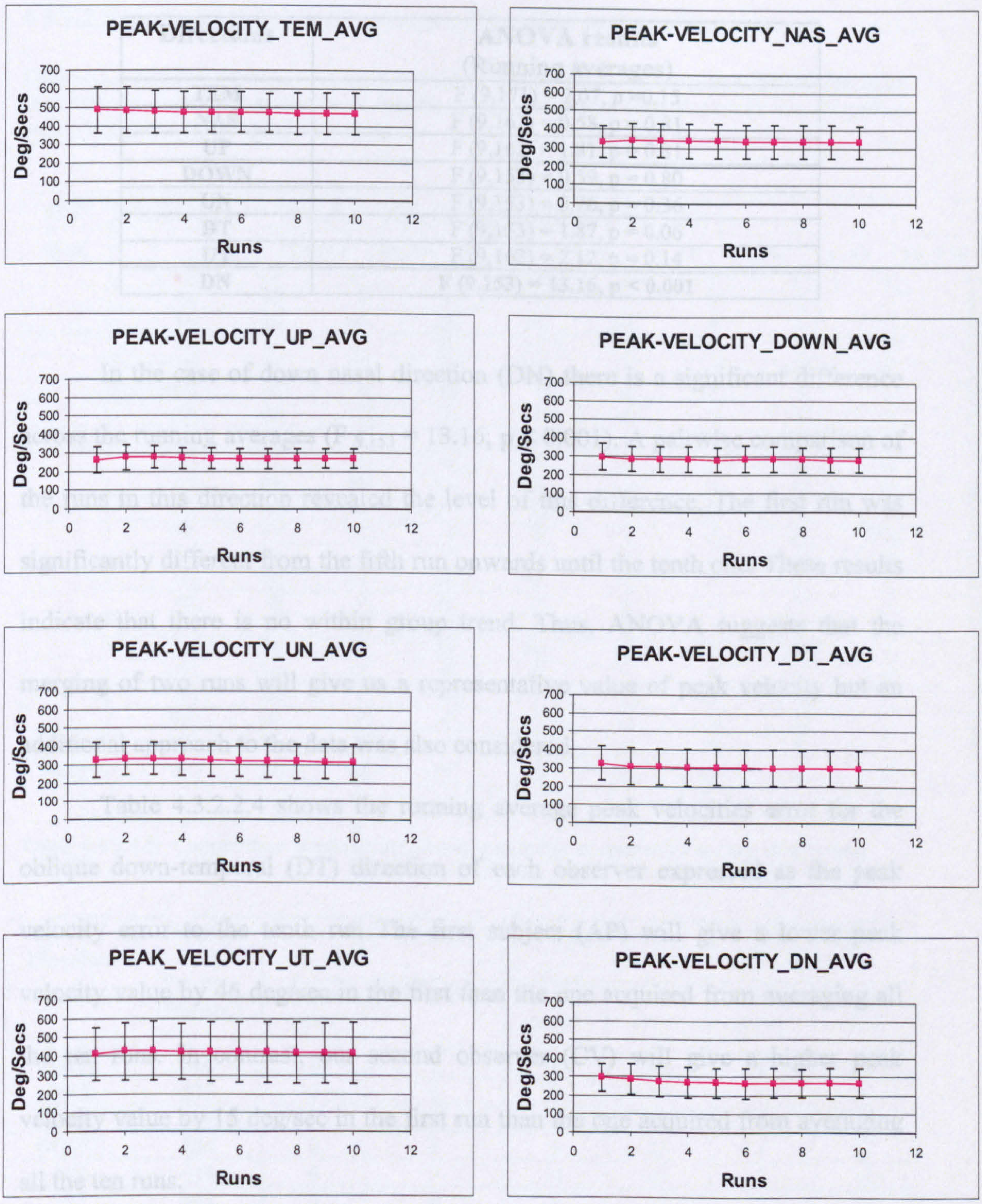


Figure 43.2.2.2: Running average of peak velocity in middle age group. Each point on these graphs are the group mean obtaining from the twenty individual measurements for peak velocity. Run number one is the group mean arising from 20 data values, run number two is the average of 40 and run number ten is the average of 200 data values. The error bars show the standard deviation for each run.

Table 4.3.2.2.3: Repeated measurements ANOVA results for the running averages.

Directions	ANOVA results (Running averages)
TEM	$F_{(9,171)} = 2.07, p = 0.15$
NAS	$F_{(9,162)} = 0.58, p = 0.81$
UP	$F_{(9,162)} = 1.81, p = 0.31$
DOWN	$F_{(9,153)} = 0.59, p = 0.80$
UN	$F_{(9,153)} = 3.26, p = 0.36$
DT	$F_{(9,153)} = 1.87, p = 0.06$
UT	$F_{(9,162)} = 2.12, p = 0.14$
* DN	**$F_{(9,153)} = 13.16, p < 0.001$**

In the case of down nasal direction (DN) there is a significant difference across the running averages ($F_{9,153} = 13.16, p < 0.001$). A pairwise comparison of the runs in this direction revealed the level of this difference. The first run was significantly different from the fifth run onwards until the tenth one. These results indicate that there is no within group trend. Thus, ANOVA suggests that the merging of two runs will give us a representative value of peak velocity but an additional approach to the data was also considered.

Table 4.3.2.2.4 shows the running average peak velocities error for the oblique down-temporal (DT) direction of each observer expressed as the peak velocity error to the tenth run The first subject (AP) will give a lower peak velocity value by 46 deg/sec in the first than the one acquired from averaging all the ten runs. In contrast, our second observer (CV) will give a higher peak velocity value by 15 deg/sec in the first run than the one acquired from averaging all the ten runs.

From the Table 4.3.2.2.4, we can see that the population mean error of the forth running average is 6 deg/sec with a standard deviation of 21 deg/sec. This decreases to a mean error of 3 deg/sec with a standard deviation of 14 deg/sec for the sixth run. The mean peak velocity of this direction is 301 deg/sec. Table 4.3.2.2.5 compares the running average of four runs to that of six runs.

Table 4.3.2.2.4: The running average peak velocities for the down-temporal (DT) direction of each subject expressed as the peak velocity error compared with the tenth run. Negative values indicate a slower peak velocity.

DT	ERRORS		PEAK VELOCITY (DEGS/SECS)							
Sxs	1	1+2	1+2+3	1+..+4	1+..+5	1+..+6	1+..+7	1+..+8	1+..+9	1+..+10
AP	-46	-26	-24	-6	-1	3	-1	2	3	0
CV	15	20	6	9	3	5	5	2	-1	0
DT	14	23	35	23	22	10	9	6	-1	0
JB	44	33	24	33	21	19	10	9	3	0
LS	//////////////	-35	-35	-47	-27	-41	-45	-27	-18	0
SL	//////////////	-5	6	18	1	4	-1	5	1	0
SA	-17	21	8	11	11	6	2	-1	2	0
DB	29	18	15	18	12	11	7	5	0	0
GC	-17	-17	-11	-8	-13	-8	-6	-5	0	0
JL	50	63	63	34	25	25	5	0	0	0
LK	27	46	40	27	19	14	10	3	1	0
SHE	119	41	4	4	-2	-2	-2	-8	-10	0
SH	45	13	9	7	6	-1	-7	-3	-3	0
BD	58	24	24	24	10	7	4	7	1	0
DK	16	-8	0	-22	-2	2	-11	-2	-6	0
GB	-69	-28	-28	2	4	-1	1	7	8	0
LB	10	34	26	28	24	18	10	7	4	0
MT	-12	-12	-18	-8	-5	-7	-5	-6	-1	0
SF	-7	10	-7	-16	-14	-7	-2	-3	1	0
TK	-15	-15	-5	-5	-5	0	3	5	2	0
average	14	10	7	6	4	3	-1	0	-1	0
stdev	43	27	24	21	14	14	12	8	5	0

Table 4.3.2.2.5: Comparison between the running average of four runs to that of six runs.

Direction	Mean Peak Velocity (Deg/sec)	AVG of 10runs		AVG of 4 runs		AVG of 6runs	
		Mean error	Stdev error	Mean error	Stdev error	Mean error	Stdev error
TEM	466	0	0	7	33	8	18
NAS	335	0	0	5	17	4	9
UP	268	0	0	3	16	1	8
DOWN	280	0	0	2	21	4	17
UN	315	0	0	14	22	7	12
DT	301	0	0	6	21	3	14
UT	417	0	0	6	30	6	10
DN	266	0	0	4	12	0	9
			Average all directions	6	22	4	12

4.3.2.3 Amplitude

The group mean of amplitudes obtained from the 20 observers in this second age group for the 10 runs in all the eight directions is shown in Figure 4.3.2.3.1. The graphs demonstrate no increasing or decreasing trend with successive measurements.

A repeated measures ANOVA was applied in each direction separately. All directions showed no significant difference (p>0.05) within the group (Table 5.3.1.3.1).

The mean and the standard deviations in each direction shown in Figure 4.3.2.3.1 are summarised in Table 4.3.2.3.2. These values give an indication of the amplitude variation arising during measurements.

Table 4.3.2.3.1: Repeated measurements ANOVA results for the individual runs.

Directions	**ANOVA results** (Individual runs)
TEM	$F(9,144) = 1.65, p = 0.11$
NAS	$F(9, 126) = 1.06, p = 0.40$
UP	$F(9, 99) = 0.82, p = 0.59$
DOWN	$F(9,108) = 0.90, p = 0.53$
UN	$F(9, 126) = 0.60, p = 0.80$
DT	$F(9, 108) = 0.59, p = 0.80$
UT	$F(9, 126) = 1.14, p = 0.34$
DN	$F(9, 90) = 2.38, p = 0.21$

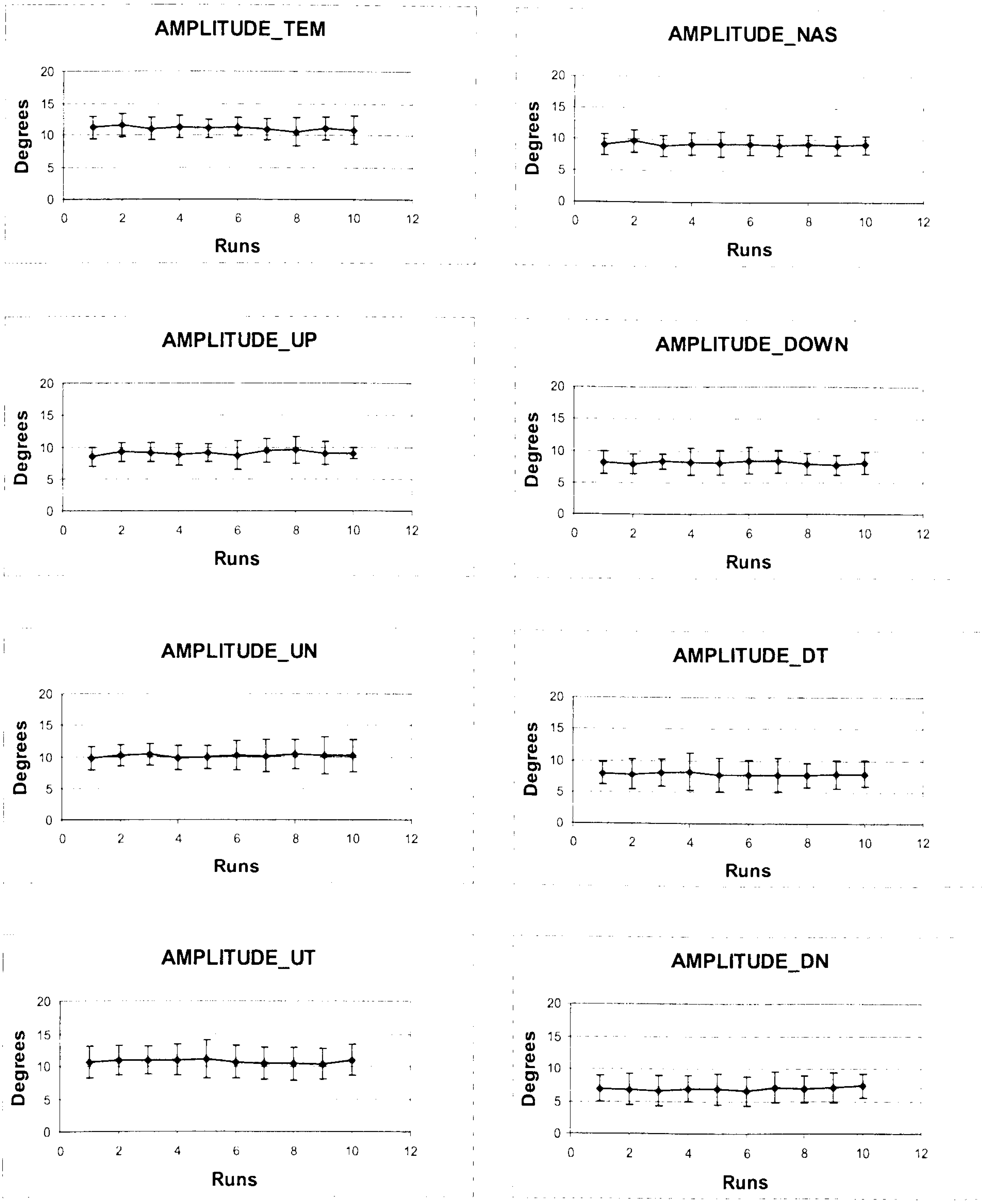


Figure 4.3.2.3.1: Each point on the graph represents the group mean obtain from the twenty individual subject measurements for amplitude. The error bars show the standard deviation for each run.

Table 4.3.2.3.2 Group mean amplitudes, standard deviations and coefficient of variation for all individual 10 runs and 20 observers in each direction separately.

Directions	*Mean Amplitude (Degrees) (Group mean)*	*Stdev*	*Coefficient of variation %*
TEM	11.03	± 1.64	15
NAS	9.16	± 1.59	17
UP	9.03	± 1.53	17
DOWN	8.04	± 1.32	16
UN	10.14	± 1.89	19
DT	7.78	± 2.15	28
UT	10.74	± 2.27	21
DN	6.79	± 2.16	32
AVERAGE FOR ALL DIRECTIONS	**9.09**	**±1.82**	**21 %**

Figure 4.3.2.3.2 represents the running averages. A visual inspection of Figure 4.3.2.3.2 reveals little change in amplitude from the first run onwards. An ANOVA revealed a non-significant difference across the running averages in all directions (Table 4.3.2.3.3).

Table 4.3.2.3.3: Repeated measurements ANOVA results for the running averages.

Directions	**ANOVA results** (Running averages)
TEM	$F(9,171) = 1.58, p = 0.12$
NAS	$F(9,162) = 1.14, p = 0.34$
UP	$F(9,162) = 3.23, p = 0.07$
DOWN	$F(9,153) = 0.21, p = 0.99$
UN	$F(9,153) = 0.52, p = 0.86$
DT	$F(9,153) = 0.21, p = 0.99$
UT	$F(9,162) = 0.63, p = 0.77$
DN	$F(9,153) = 1.20, p = 0.30$

Thus Figure 4.3.2.3.2 and ANOVA suggest that a representative value of amplitude may be achieved from a single run. Table 4.3.2.3.4 shows the running average amplitude error for the oblique up temporal (UT) direction of each observer expressed as the amplitude error compared to the tenth one.

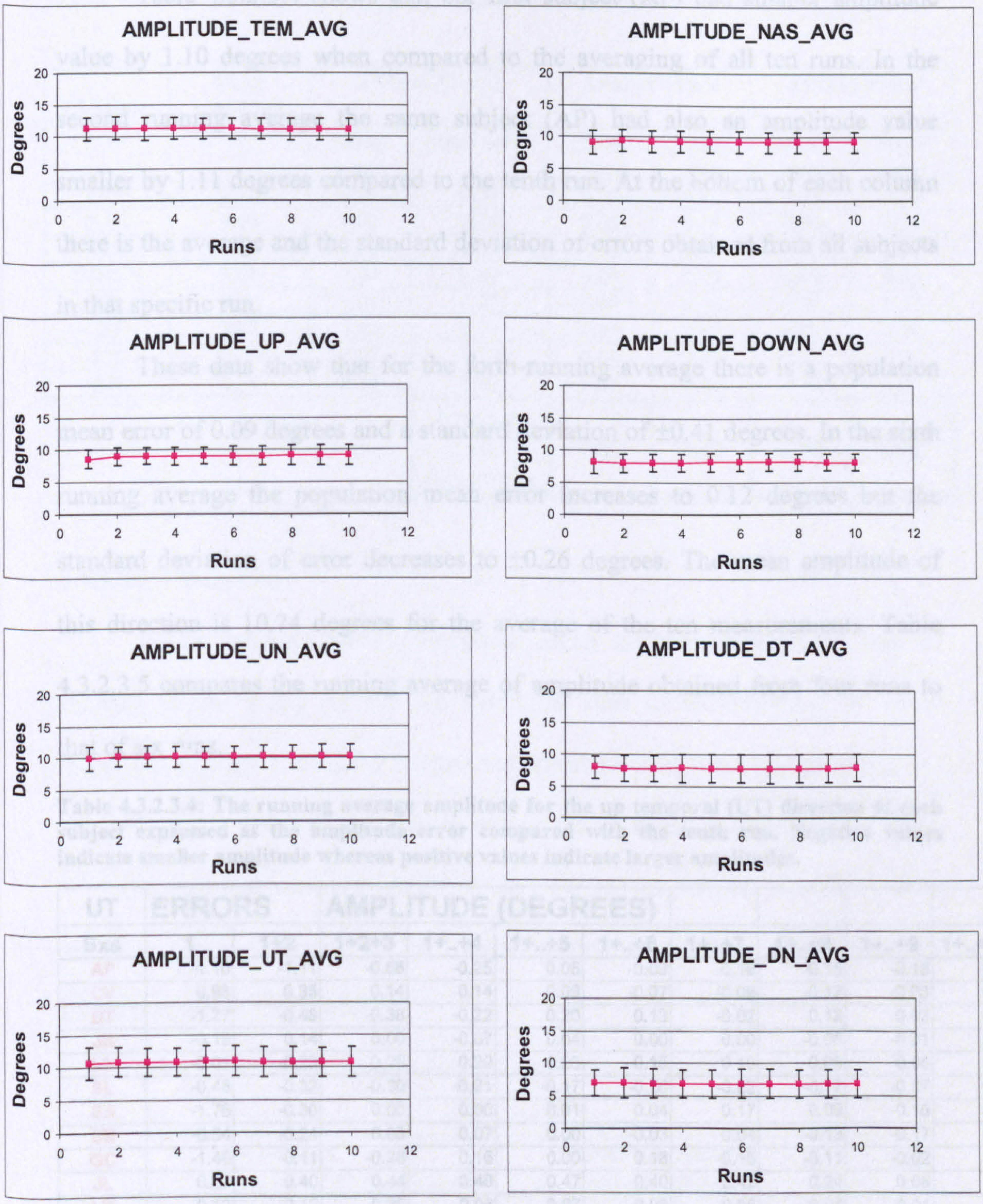


Figure 4.3.2.3.2: Running averages for amplitude. Each point on these graphs are the group mean obtaining from the twenty individual measurements for amplitude. Run number one is the group mean arising from 20 data values, run number two is the average of 40 and run number ten is the average of 200 data values. The error bars show the standard deviation for each run

Table 4.3.2.3.4 shows that our first subject (AP) had smaller amplitude value by 1.10 degrees when compared to the averaging of all ten runs. In the second running average the same subject (AP) had also an amplitude value smaller by 1.11 degrees compared to the tenth run. At the bottom of each column there is the average and the standard deviation of errors obtained from all subjects in that specific run.

These data show that for the forth-running average there is a population mean error of 0.09 degrees and a standard deviation of ±0.41 degrees. In the sixth running average the population mean error increases to 0.12 degrees but the standard deviation of error decreases to ±0.26 degrees. The mean amplitude of this direction is 10.74 degrees for the average of the ten measurements. Table 4.3.2.3.5 compares the running average of amplitude obtained from four runs to that of six runs.

Table 4.3.2.3.4: The running average amplitude for the up temporal (UT) direction of each subject expressed as the amplitude error compared with the tenth run. Negative values indicate smaller amplitude whereas positive values indicate larger amplitudes.

UT	ERRORS		AMPLITUDE (DEGREES)							
Sxs	1	1+2	1+2+3	1+..+4	1+..+5	1+..+6	1+..+7	1+..+8	1+..+9	1+..+10
AP	-1.10	-1.11	-0.56	-0.25	0.06	-0.03	-0.18	-0.15	-0.15	0.00
CV	0.98	0.35	0.14	0.14	0.09	-0.07	-0.09	-0.12	-0.03	0.00
DT	-1.27	-0.48	-0.38	-0.22	0.20	0.13	-0.02	0.12	0.03	0.00
JB	-0.19	0.14	0.00	-0.07	0.04	0.00	0.00	-0.05	-0.01	0.00
LS	-0.01	-0.23	0.25	0.29	0.25	0.15	0.10	0.09	0.06	0.00
SL	-0.48	-0.32	-0.30	-0.21	-0.17	-0.26	-0.22	-0.17	-0.07	0.00
SA	-1.76	-0.30	0.00	0.00	0.01	0.04	0.17	0.09	-0.16	0.00
DB	-0.54	-0.24	0.03	0.07	0.00	-0.03	0.04	-0.13	-0.17	0.00
GC	-1.49	-0.11	-0.28	0.16	0.00	0.18	-0.15	-0.11	-0.02	0.00
JL	0.27	0.40	0.44	0.40	0.47	0.40	0.42	0.24	0.08	0.00
LK	0.12	0.12	0.36	0.06	0.07	-0.08	-0.05	-0.04	-0.01	0.00
SHE	//////////////	-0.58	-0.53	-0.61	0.30	0.43	0.43	0.43	0.00	0.00
SH	1.12	0.80	1.44	0.96	0.61	0.32	0.34	0.20	0.12	0.00
BD	0.74	0.12	-0.22	0.12	0.41	0.47	0.21	0.07	-0.08	0.00
DK	3.15	1.81	1.42	1.06	0.87	0.65	0.27	0.00	0.00	0.00
GB	-1.01	-0.42	-0.54	-0.48	-0.42	-0.38	-0.28	-0.19	-0.13	0.00
LB	0.44	0.56	0.60	0.32	0.29	-0.06	0.00	0.08	0.04	0.00
MT	0.13	0.54	-0.34	-0.15	0.05	0.11	0.04	0.06	0.02	0.00
SF	0.08	0.53	0.35	0.35	0.44	0.43	0.24	0.19	0.06	0.00
TK	0.07	-0.06	-0.06	-0.06	-0.37	0.07	0.37	0.20	0.01	0.00
average	**-0.04**	**0.08**	**0.09**	**0.09**	**0.16**	**0.12**	**0.08**	**0.04**	**-0.02**	**0.00**
stdev	**1.12**	**0.62**	**0.57**	**0.41**	**0.31**	**0.26**	**0.22**	**0.16**	**0.08**	**0.00**

Table 4.3.2.3.5: Comparison between the running average of four runs to that of six runs.

Direction	Mean Amplitude (Degrees)	AVG of 10runs		AVG of 4 runs		AVG of 6runs	
		Mean error	Stdev error	Mean error	Stdev error	Mean error	Stdev error
TEM	11.03	0.00	0.00	0.17	0.44	0.15	0.32
NAS	9.16	0.00	0.00	0.02	0.36	0.03	0.19
UP	9.03	0.00	0.00	-0.09	0.51	-0.09	0.28
DOWN	8.04	0.00	0.00	0.03	0.70	0.08	0.45
UN	10.14	0.00	0.00	0.00	0.70	-0.04	0.47
DT	7.78	0.00	0.00	0.03	0.40	-0.04	0.30
UT	10.74	0.00	0.00	0.09	0.41	0.12	0.26
DN	6.79	0.00	0.00	0.02	0.26	-0.01	0.25
			Average all directions	0.03	0.47	0.03	0.32

4.3.2.4 Duration

Figure 4.3.2.4.1 shows the group mean duration obtained for the 20 subjects in this group for the ten individual runs in all directions. A visual inspection of Figure 4.3.2.4.1 reveals that duration values in this age group are relatively stable with a small variation among the observers in some directions.

A repeated measures ANOVA was applied in this set of data in each direction separately. Table 4.3.2.4.1 shows a summary of those ANOVA results for each direction respectively.

Table 4.3.2.4.1: Repeated measurements ANOVA results for the individual runs.

Directions	ANOVA results (Individual runs)
TEM	$F(9,144) = 0.83, p = 0.60$
NAS	$F(9,126) = 1.62, p = 0.12$
UP	$F(9,99) = 1.12, p = 0.35$
DOWN	$F(9,108) = 1.13, p = 0.35$
UN	$F(9,126) = 2.42, p = 0.16$
DT	$F(9,108) = 1.11, p = 0.36$
UT	$F(9,117) = 0.61, p = 0.79$
DN	$F(9,90) = 1.27, p = 0.26$

All directions showed no significant difference ($p>0.05$) within the group between any of the ten runs. Therefore there appears to be no within trend arising from factors such as fatigue, learning or changes in attention.

Table 4.3.2.4.2 shows a summary of the mean durations and the standard deviations in each direction shown in Figure 4.3.2.4.1.

Table 4.3.2.4.2: Group mean durations, standard deviations and coefficient of variation for all individual 10 runs and 20 observers in each direction separately.

Directions	*Mean Duration (msecs) (Group mean)*	*Stdev*	*Coefficient of variation %*
TEM	43	± 6	15
NAS	46	± 7	15
UP	65	± 18	27
DOWN	48	± 8	17
UN	66	± 21	33
DT	42	± 6	14
UT	51	± 15	28
DN	42	± 6	15
AVERAGE FOR ALL DIRECTIONS	**50**	**±11**	**21 %**

Figure 4.3.2.4.2 represents the running averages. A visual inspection of Figure 4.3.2.4.2 reveals little variation in duration values from the first run in some directions. ANOVA revealed a non-significant difference across the averaged ten runs in all directions (Table 4.3.2.4.3). Thus Figure 4.3.2.1.2 and ANOVA suggest that even one run may give a representative duration value.

Table 4.3.2.4.3: Repeated measurements ANOVA results for the running averages.

Directions	**ANOVA results** (Running averages)
TEM	$F(9,171) = 4.02, p = 0.18$
NAS	$F(9,162) = 4.56, p = 0.34$
UP	$F(9,162) = 1.06, p = 0.40$
DOWN	$F(9,153) = 1.91, p = 0.16$
UN	$F(9,153) = 1.33, p = 0.23$
DT	$F(9,153) = 1.19, p = 0.31$
UT	$F(9,162) = 0.22, p = 0.99$
DN	$F(9,153) = 7.48, p = 0.14$

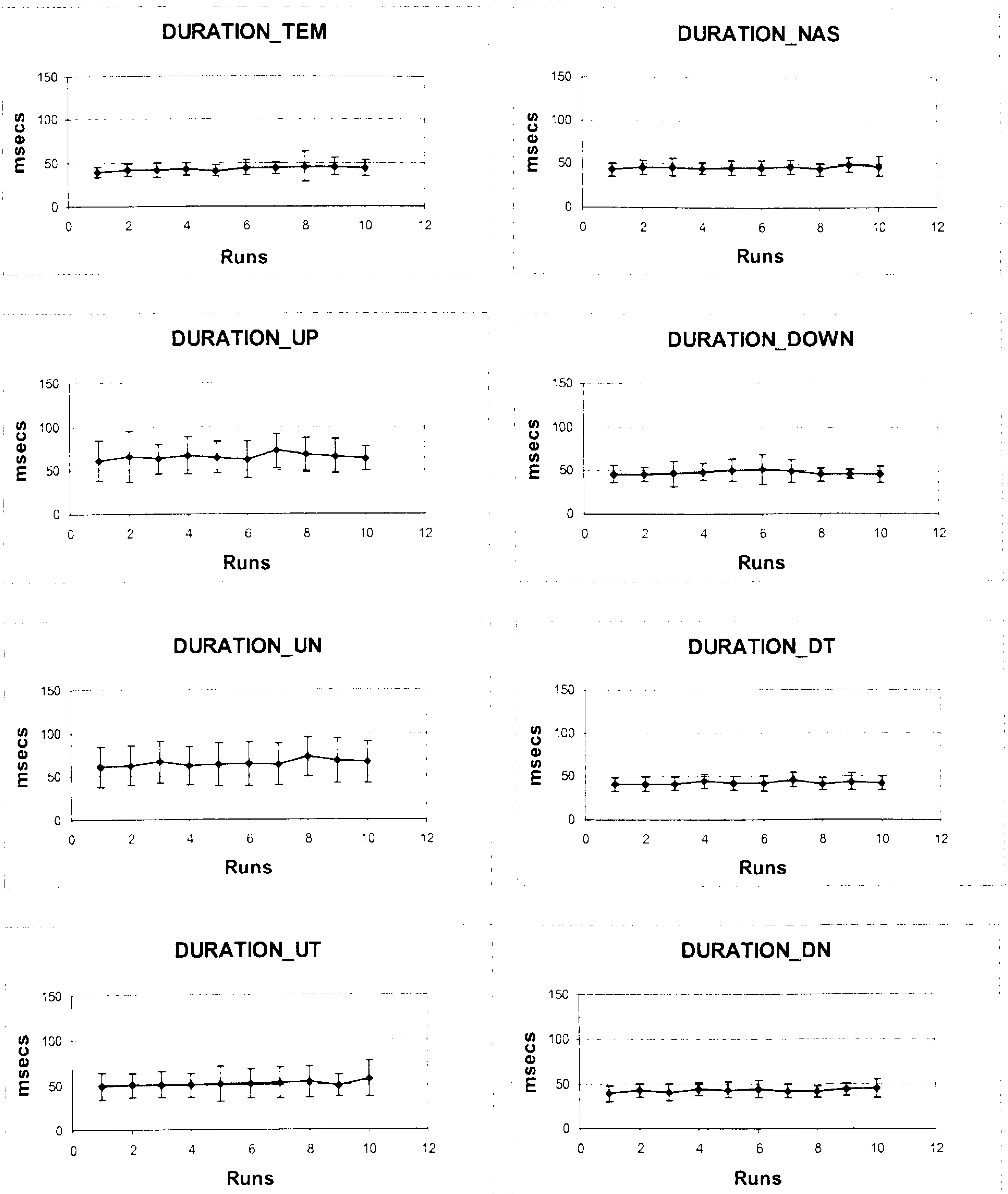


Figure 4.3.2.4.1: Each point on the graph represents the group mean obtain from the twenty individual subject measurements for duration. The error bars are ±1 standard deviation for each run.

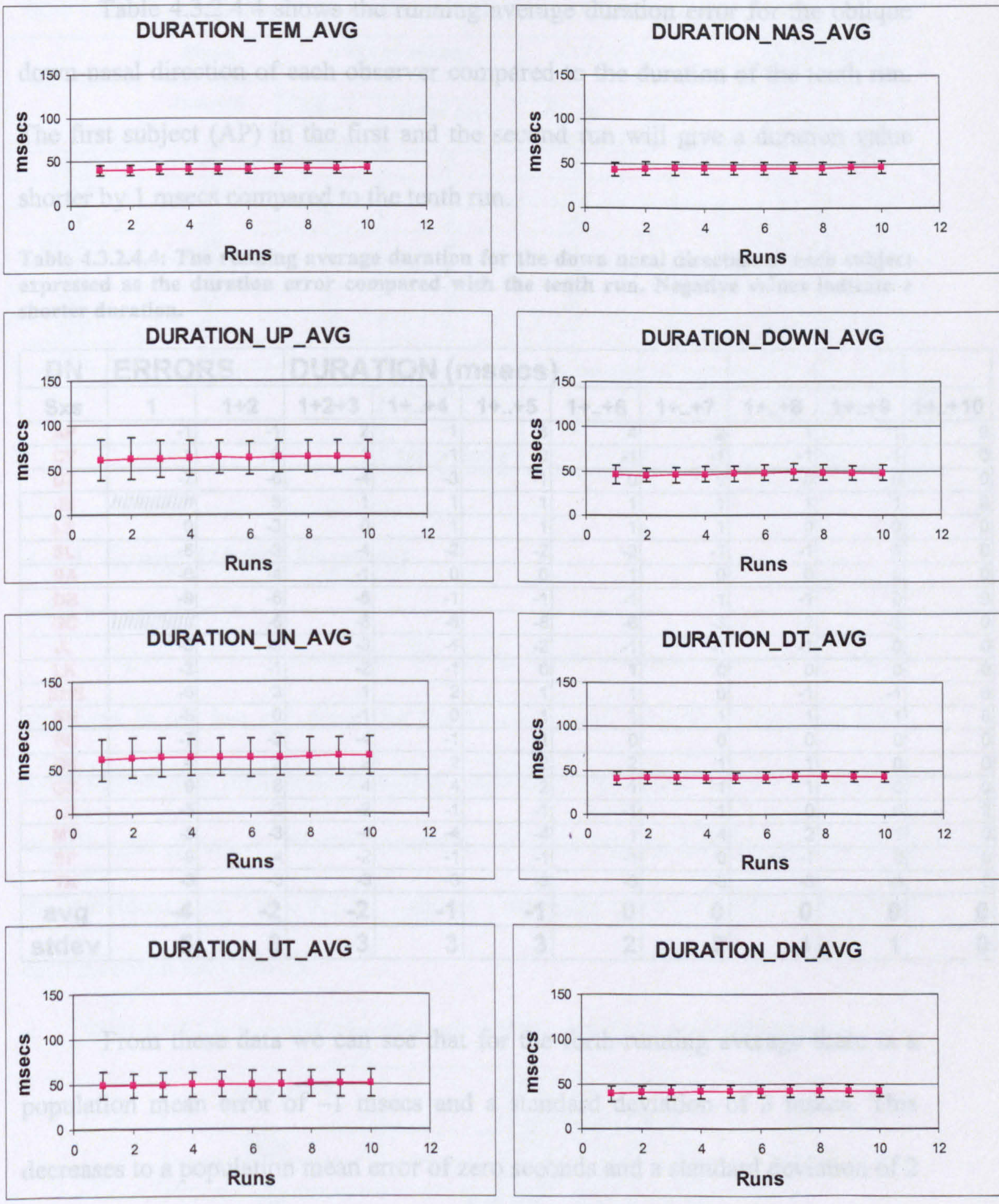


Figure 4.3.2.4.2: Running averages for duration. Each point on these graphs are the group mean obtaining from the twenty individual measurements for duration. Run number one is the group mean arising from 20 data values, run number two is the average of 40 and run number ten is the average of 200 data values. The error bars are standard deviations for each run

Table 4.3.2.4.4 shows the running average duration error for the oblique down-nasal direction of each observer compared to the duration of the tenth run. The first subject (AP) in the first and the second run will give a duration value shorter by 1 msecs compared to the tenth run.

Table 4.3.2.4.4: The running average duration for the down nasal direction of each subject expressed as the duration error compared with the tenth run. Negative values indicate a shorter duration.

DN	ERRORS		DURATION (msecs)							
Sxs	1	1+2	1+2+3	1+..+4	1+..+5	1+..+6	1+..+7	1+..+8	1+..+9	1+..+10
AP	-1	-1	2	1	3	4	2	1	1	0
CV	1	0	1	-1	0	-1	-1	-1	-1	0
DT	-7	-6	-4	-3	-1	0	0	0	0	0
JB	//////////////	5	1	1	1	1	1	1	1	0
LS	0	-3	0	1	1	1	1	0	0	0
SL	-6	-3	-4	-2	-2	-2	-1	-1	0	0
SA	-6	-4	-1	0	0	1	0	0	0	0
DB	-9	-6	-5	-1	-1	-1	-1	-1	0	0
GC	//////////////	-6	-8	-8	-8	-6	-3	-3	-3	0
JL	-3	-3	-3	-1	-2	-1	-1	-1	0	0
LK	-3	-1	-2	-1	0	1	0	0	0	0
SHE	-6	3	1	2	1	1	0	-1	-1	0
SH	-8	0	-1	0	1	1	1	1	1	0
BD	-7	-2	-4	-1	-1	0	0	0	0	0
DK	4	2	2	2	2	2	1	1	0	0
GB	9	6	4	4	2	1	1	1	0	0
LB	-5	-2	-2	-1	-1	-1	-1	0	0	0
MT	-5	-3	-4	-4	-4	1	4	2	1	0
SF	-9	-4	-2	-1	-1	-1	0	-1	0	0
TK	-3	-3	-3	-3	-3	-3	-3	-3	-3	0
avg	**-4**	**-2**	**-2**	**-1**	**-1**	**0**	**0**	**0**	**0**	**0**
stdev	**5**	**3**	**3**	**3**	**3**	**2**	**2**	**1**	**1**	**0**

From these data we can see that for the forth-running average there is a population mean error of –1 msecs and a standard deviation of 3 msecs. This decreases to a population mean error of zero seconds and a standard deviation of 2 msecs for the sixth running average. The mean duration of this direction is 42 msecs for the average of ten measurements. Table 4.3.2.4.5 compares the four running average to the one obtained of a six run assessment.

Table 4.3.2.4.5: Comparison between the running average of four runs to that of six runs.

Direction	Mean Duration (msecs)	AVG of 10runs		AVG of 4 runs		AVG of 6runs	
		Mean error	Stdev error	Mean error	Stdev error	Mean error	Stdev error
TEM	43	0	0	-2	4	-1	3
NAS	46	0	0	-1	3	-1	2
UP	65	0	0	-1	6	-1	3
DOWN	48	0	0	-1	3	0	2
UN	66	0	0	-2	3	-2	3
DT	42	0	0	0	2	-1	2
UT	51	0	0	-1	4	-1	2
DN	42	0	0	-1	3	0	2
			Average all directions	**-1**	**4**	**-1**	**2**

4.3.3 Group III (60-80 years)

4.3.3.1 Latency:

Figure 4.3.3.1.1 represents the group mean latencies obtained for the 20 observers in our last age group for the 10 runs in all directions. This age group have shown the highest intersubject variability compared to the young and middle-aged group. A repeated measures ANOVA was applied in the data set of the individual runs. Table 4.3.3.1.1 shows a summary of those ANOVA results for each direction respectively.

Table 4.3.3.1.1: Repeated measurements ANOVA results for the individual runs.

Directions	ANOVA results (Individual runs)
TEM	$F(9,90) = 3.30, p = 0.06$
* NAS	**$F(9,108) = 2.47, p = 0.01$**
* UP	**$F(9,108) = 4.43, p < 0.001$**
* DOWN	**$F(9,108) = 3.30, p = 0.001$**
UN	$F(9,90) = 2.25, p = 0.09$
DT	$F(9,63) = 1.63, p = 0.13$
UT	$F(9,90) = 2.87, p = 0.22$
DN	$F(9,90) = 1.50, p = 0.16$

All directions showed no significant difference ($p>0.05$) within the group between any of the ten runs apart from the nasal (NAS) and the vertical directions.

A pairwise comparison between the ten runs in the nasal direction revealed only a difference between the first and the forth-individual run ($p = 0.04$). In the case of the up direction, the within subjects test showed a significant different effect ($F_{9,108} = 4.43$, $p < 0.001$). Pairwise comparisons revealed a significant difference between the first and the forth ($p = 0.03$), the sixth ($p = 0.03$) and the seventh ($p = 0.02$) run. The sixth run of this direction was also different to the ninth ($p = 0.02$) individual run. In addition, in the down direction, pairwise comparisons showed a borderline significance between the mean latency of the first and the forth run ($p = 0.05$), and a significant difference to the fifth run ($p = 0.01$). Overall, there appears to be no within trend arising from factors such as fatigue, learning or changes in attention. The mean and the standard deviations in each direction shown in Figure 4.3.3.1.1 are summarised in Table 4.3.3.1.2.

Table 4.3.3.1.2: Mean latencies, standard deviations and coefficient of variation for all individual 10 runs and 20 observers in each direction separately.

Directions	*Mean Latency (msecs) (Group mean)*	*Stdev*	*Coefficient of variation %*
TEM	293	± 52	18
NAS	271	± 32	12
UP	278	± 31	11
DOWN	297	± 42	14
UN	285	± 44	15
DT	303	± 48	16
UT	288	± 47	16
DN	295	± 46	15
AVERAGE FOR ALL DIRECTIONS	**289**	**±43**	**15 %**

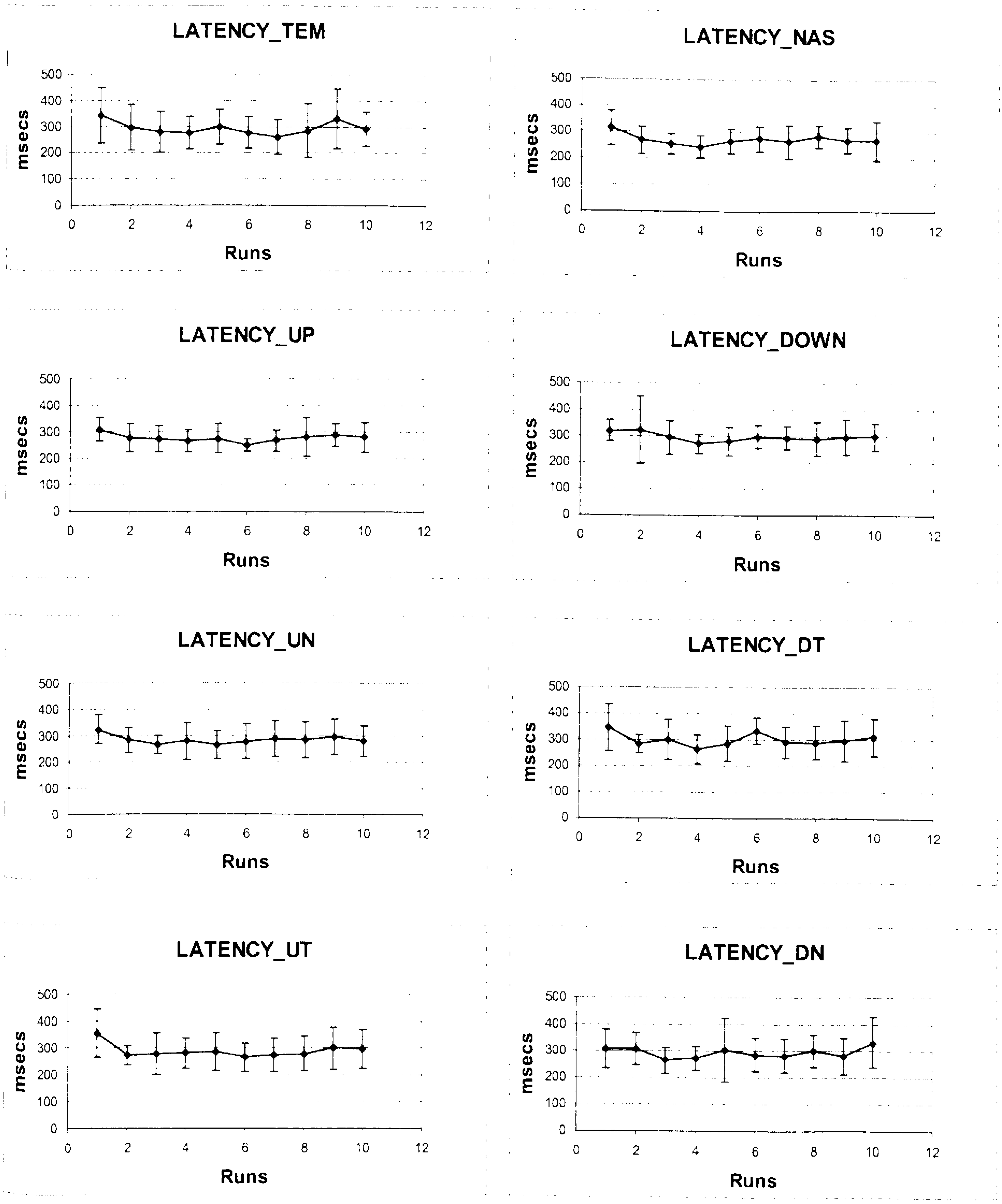


Figure 4.3.3.1.1: Each point on the graph represents the group mean obtain from the twenty individual subject measurements for latency. The error bars show the standard deviations.

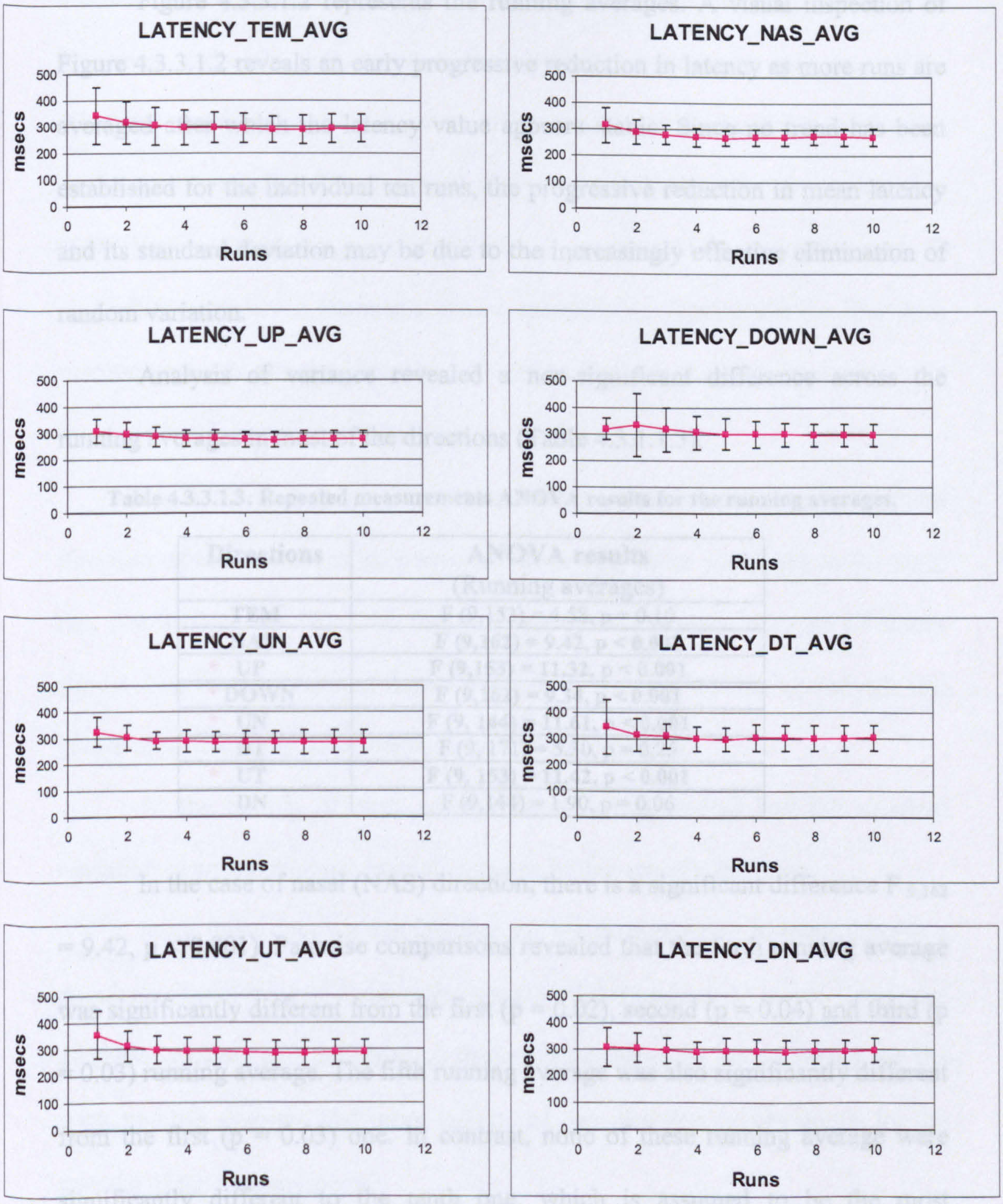


Figure 4.3.3.1.2: Running averages for latency in Group III (ranged 60-89 years). Each point on these graphs are the group mean obtaining from the twenty individual measurements for latency. Run number one is the group mean arising from 20 data values, run number two is the average of 40 and run number ten is the average of 200 data values. The error bars show ±1 STDEV for each run.

Figure 4.3.3.1.2 represents the running averages. A visual inspection of Figure 4.3.3.1.2 reveals an early progressive reduction in latency as more runs are averaged after which the latency value appears stable. Since no trend has been established for the individual ten runs, the progressive reduction in mean latency and its standard deviation may be due to the increasingly effective elimination of random variation.

Analysis of variance revealed a non-significant difference across the running averages in most of the directions (Table 4.3.1.1.3).

Table 4.3.3.1.3: Repeated measurements ANOVA results for the running averages.

Directions	ANOVA results (Running averages)
TEM	$F(9,153) = 4.58, p = 0.10$
* **NAS**	$\mathbf{F(9,162) = 9.42, p < 0.001}$
* **UP**	$\mathbf{F(9,153) = 11.32, p < 0.001}$
* **DOWN**	$\mathbf{F(9,162) = 9.34, p < 0.001}$
* **UN**	$\mathbf{F(9, 144) = 11.61, p < 0.001}$
DT	$F(9, 171) = 5.30, p = 0.25$
* **UT**	$\mathbf{F(9, 153) = 11.42, p < 0.001}$
DN	$F(9,144) = 1.90, p = 0.06$

In the case of nasal (NAS) direction, there is a significant difference $F_{9,162} = 9.42$, $p < 0.001$). Pairwise comparisons revealed that the forth running average was significantly different from the first ($p = 0.02$), second ($p = 0.04$) and third ($p = 0.03$) running average. The fifth running average was also significantly different from the first ($p = 0.03$) one. In contrast, none of these running average were significantly different to the tenth one, which is assumed to be the most representative one in this set of data. The results stabilise at the forth running average. Other directions that also indicated a significant difference among the ten runs were the ones with an upward component (UP: $F_{9,153} = 11.32$, $p < 0.001$; UN: $F_{9,144} = 11.61$, $p < 0.001$; UT: $F_{9,153} = 11.42$, $p < 0.001$). In these directions, the first running average was significantly different to the merging of four, five, six, seven and eight runs. None of these running averages in each one of the directions mentioned previously, were different to the tenth one that is assumed to be the most accurate. The statistical analysis (ANOVA) in the down direction (DOWN) also revealed significant differences across the ten running averages ($F_{9,162} = 9.34$, $p < 0.001$). Planned pairwise comparisons showed that the first three running averages are significantly different to the one obtained from averaging five ($p = 0.004$) and six ($p = 0.01$) runs.

Table 4.3.3.1.4 shows the running average latencies error for the temporal direction of each observer expressed as the latency error compared to the tenth run. For subject one (EB) the first run will give a latency value of 20 msecs shorter than the one acquired from averaging all ten runs and the second run will give a value longer by 36 msecs compared to the tenth run.

At the bottom of each column there is the average and the standard deviation of errors obtained from all subjects in that specific direction.

From these data we can see that for the forth running average there is a population mean error of 4 msecs and a standard deviation of 23 msecs. The mean decreases to zero and the standard deviation decreases to the 18 msecs for the sixth running average. The mean latency of this direction is 293 msecs for the average of ten measurements.

We examined the other seven directions, which are summarised in Table 4.3.3.1.5 where the running averages based on four runs are compared to those based on six runs.

Table 4.3.3.1.4: The running average latencies for the temporal direction of each subject expressed as the latency error compared with the tenth run. Negative values indicate a shorter latency.

TEM	ERRORS		LATENCY (msecs)							
SXS	1	1+2	1+2+3	1+..+4	1+..+5	1+..+6	1+..+7	1+..+8	1+..+9	1+..+10
EB	-20	36	47	26	22	20	0	0	0	0
HC	-87	-61	-44	-36	-43	-42	-40	0	-1	0
IG	181	94	67	47	26	9	-5	-9	1	0
JO	28	28	28	15	33	28	26	14	6	0
MS	-3	-9	1	13	3	-9	-15	-16	-9	0
VG	32	32	17	-2	6	4	5	2	-2	0
WS	21	1	-2	0	8	5	2	0	0	0
BW	20	1	-18	-20	-20	-12	-12	-8	-9	0
ES	61	22	3	5	6	-1	-3	-5	-1	0
HR	83	96	45	29	8	7	7	5	6	0
JHE	52	13	0	1	1	3	2	-2	1	0
JR	-15	-18	-23	-1	1	-7	-8	-8	-3	0
WC	//////////////	26	14	-3	-3	-9	-11	-3	0	0
DBE	//////////////	16	19	32	29	14	15	23	12	0
HO	-114	-114	-36	-40	5	18	-21	-47	-9	0
IB	186	90	49	27	18	11	2	4	5	0
JHO	146	57	22	-4	-12	-21	-28	-30	4	0
MBU	266	132	92	53	38	20	9	0	-6	0
RT	14	-14	-28	-34	-19	-10	-9	-1	-1	0
WHS	21	21	-45	-36	-45	-27	-11	-15	1	0
avg	**48**	**23**	**10**	**4**	**3**	**0**	**-5**	**-5**	**0**	**0**
stdev	**95**	**56**	**37**	**27**	**23**	**18**	**15**	**15**	**6**	**0**

Table 4.3.3.1.5: Comparison between the running average of four runs to that of six runs.

Direction	Mean latency (msecs)	AVG of 10runs		AVG of 4 runs		AVG of 6runs	
		Mean error	Stdev error	Mean error	Stdev error	Mean error	Stdev error
TEM	293	0.00	0.00	4	27	0	18
NAS	271	0.00	0.00	-2	22	-2	12
UP	278	0.00	0.00	3	17	-3	13
DOWN	297	0.00	0.00	9	32	2	18
UN	285	0.00	0.00	5	25	-2	13
DT	303	0.00	0.00	-2	24	1	13
UT	288	0.00	0.00	6	24	-1	19
DN	295	0.00	0.00	8	27	-4	13
			Average all directions	2	25	-1	15

4.3.3.2 Peak Velocity:

The same analysis was also followed in this saccadic parameter for the elderly age group. Figure 4.3.3.2.1 show the group mean peak velocity for the 20 subjects in the elderly for all 10 runs in all the directions under investigation. A repeated measures ANOVA was applied in all eight directions for the individual runs separately. Table 4.3.3.2.1 summarizes the results of those individual runs ANOVA results for each direction.

Table 4.3.3.2.1: Repeated measurements ANOVA results for the individual runs.

Directions	ANOVA results (Individual runs)
TEM	$F(9,90) = 0.90, p = 0.53$
NAS	$F(9,108) = 1.29, p = 0.25$
UP	$F(9,108) = 0.94, p = 0.49$
DOWN	$F(9,108) = 0.61, p = 0.78$
UN	$F(9.90) = 1.08, p = 0.38$
DT	$F(9, 63) = 0.84, p = 0.58$
UT	$F(9,90) = 0.47, p = 0.88$
DN	$F(9,90) = 1.35, p = 0.22$

All directions showed no significant difference ($p>0.05$) within the group between any of the ten runs. There appears to be no within trend arising from factors such as fatigue, learning or changes in attention. The mean and the standard deviations in each direction shown in Figure 4.3.3.2.1 are summarised in Table 4.3.3.2.2. These values give an indication of the peak velocity variation arising during measurements.

The mean peak velocities illustrated in Figure 4.3.3.2.1 show no significant change across the ten runs for the eight directions.

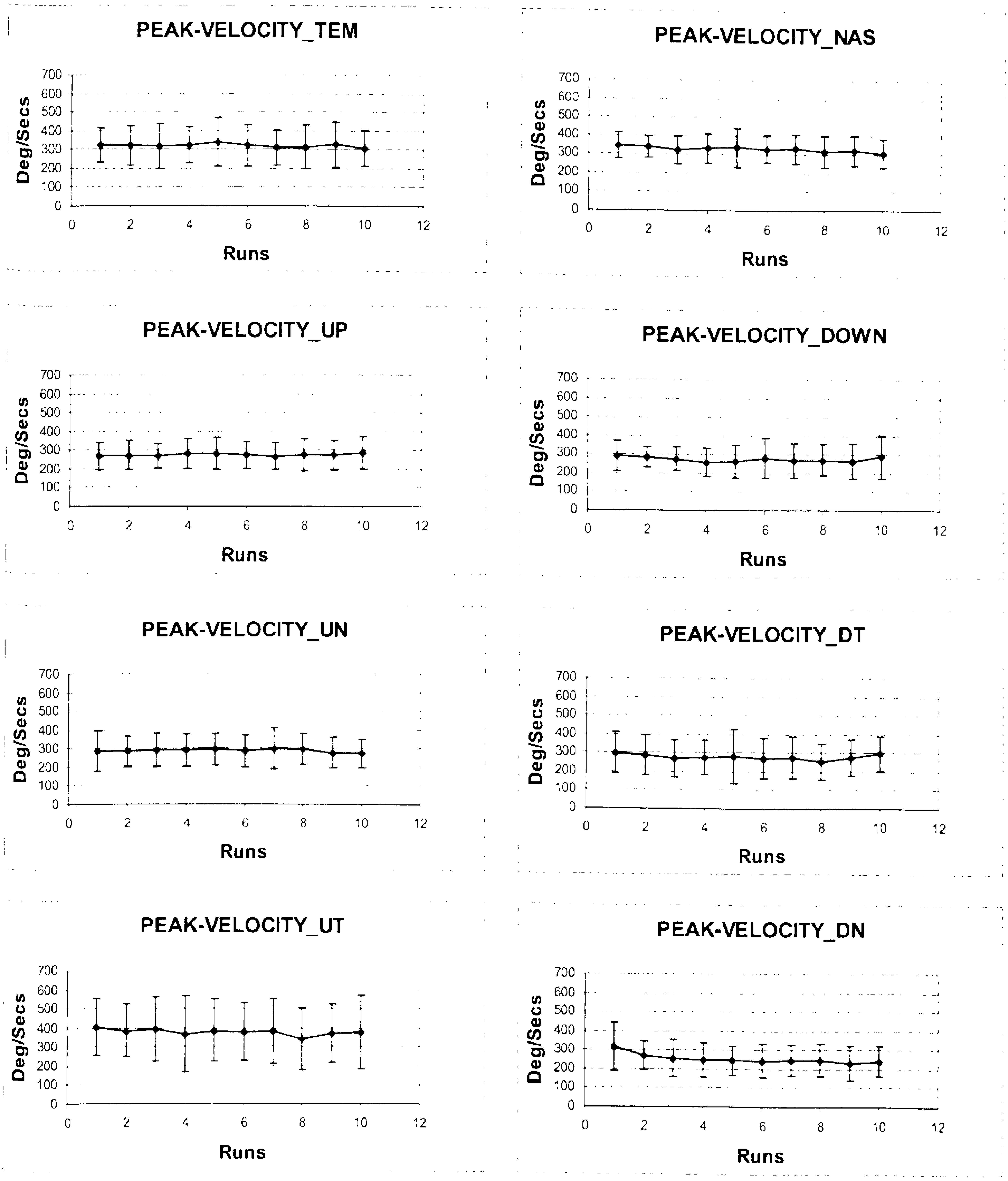


Figure 4.3.3.2.1: Each point on the graph represents the group mean obtain from the twenty individual subject measurements for peak velocity. The bars show the standard deviation for each run, thus the intersubject variability.

Table 4.3.3.2.2: Group mean peak velocities, standard deviations and coefficient of variation for all individual 10 runs and 20 observers in each direction separately.

Directions	*Mean Peak Velocity (Deg/sec) (Group mean)*	*Stdev*	*Coefficient of variation %*
TEM	320	± 98	31
NAS	329	± 70	21
UP	273	± 71	26
DOWN	274	± 70	25
UN	294	± 80	27
DT	272	± 92	34
UT	376	± 152	40
DN	250	± 80	32
AVERAGE FOR ALL DIRECTIONS	**299**	**±89**	**30 %**

Figure 4.3.3.2.2 represents the running averages. A visual inspection of Figure 4.3.3.2.2 reveals a stable peak velocity even from the first run in some directions. The statistical analysis (repeated measures ANOVA) also revealed a non-significant difference across the running averages in all directions (Table 4.3.3.2.3).

Table 4.3.3.2.3: Repeated measures ANOVA results for the running averages.

Directions	**ANOVA results** (Running averages)
TEM	$F(9,153) = 1.54, p = 0.14$
NAS	$F(9,162) = 1.78, p = 0.08$
UP	$F(9,153) = 1.03, p = 0.42$
DOWN	$F(9,162) = 3.60, p = 0.42$
UN	$F(9,144) = 0.36, p = 0.95$
DT	$F(9,171) = 3.87, p = 0.57$
UT	$F(9,153) = 1.13, p = 0.34$
DN	$F(9,144) = 1.98, p = 0.16$

The suggestion from these ANOVA results is that even a single measurement will give us a representative value of peak velocity.

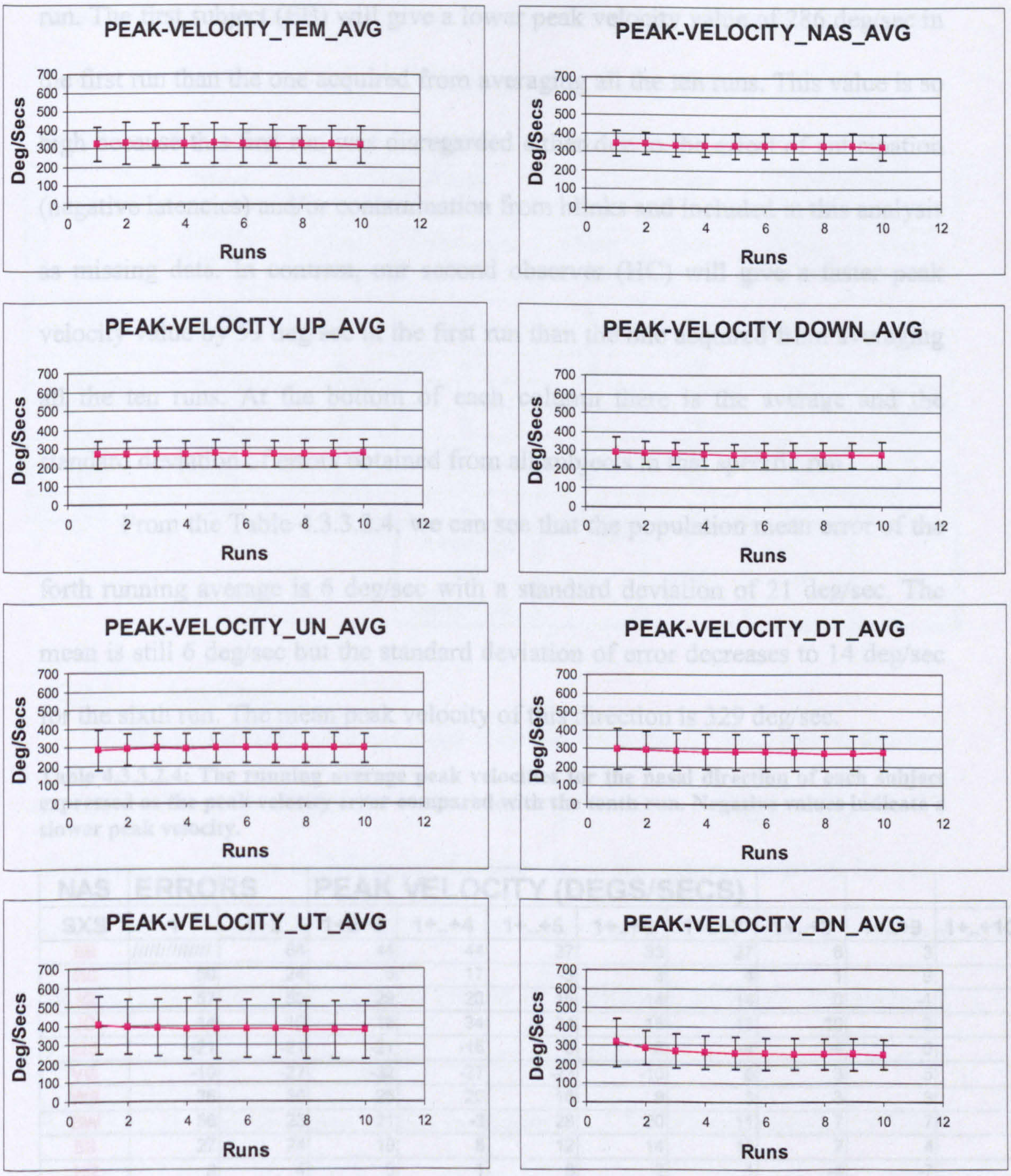


Figure 4.3.3.2.2: Running averages for peak velocity. Each point on these graphs are the group mean obtaining from the twenty individual measurements for peak velocity. Run number one is the group mean arising from 20 data values, run number two is the average of 40 and run number ten is the average of 200 data values. The error bars show standard deviations for each run.

Table 4.3.3.2.4 shows the running average peak velocities error for the nasal direction of each observer expressed as the peak velocity error to the tenth run. The first subject (EB) will give a lower peak velocity value of 286 deg/sec in the first run than the one acquired from averaging all the ten runs. This value is so high because this first run was disregarded either due to the effect of anticipation (negative latencies) and/or contamination from blinks and included in this analysis as missing data. In contrast, our second observer (HC) will give a faster peak velocity value by 59 deg/sec in the first run than the one acquired from averaging all the ten runs. At the bottom of each column there is the average and the standard deviation of errors obtained from all subjects in that specific run.

From the Table 4.3.3.2.4, we can see that the population mean error of the forth running average is 6 deg/sec with a standard deviation of 21 deg/sec. The mean is still 6 deg/sec but the standard deviation of error decreases to 14 deg/sec for the sixth run. The mean peak velocity of this direction is 329 deg/sec.

Table 4.3.3.2.4: The running average peak velocities for the nasal direction of each subject expressed as the peak velocity error compared with the tenth run. Negative values indicate a slower peak velocity.

NAS	ERRORS		PEAK VELOCITY (DEGS/SECS)							
SXS	1	1+2	1+2+3	1+..+4	1+..+5	1+..+6	1+..+7	1+..+8	1+..+9	1+..+10
EB	////////////	64	44	44	37	33	27	6	3	0
HC	59	24	6	17	-3	3	4	1	9	0
IG	57	50	29	20	15	14	14	0	-1	0
JO	-14	10	18	34	34	18	13	10	2	0
MS	-21	-21	-21	-16	-9	-8	-4	-4	0	0
VG	-10	-27	-32	-27	-23	-10	0	3	5	0
WS	36	36	25	20	16	9	3	3	3	0
BW	56	23	21	-3	28	20	11	7	7	0
ES	27	24	19	8	12	14	10	7	4	0
HR	8	4	5	1	8	2	1	-4	-7	0
JHE	0	16	21	16	16	13	11	5	0	0
JR	31	22	16	16	8	3	4	2	1	0
WC	124	83	52	36	32	21	16	13	7	0
DBE	-19	-48	-48	-29	-17	-10	-11	-6	0	0
HO	-14	-14	-20	4	4	4	10	14	13	0
IB	-17	11	8	7	2	5	-1	-3	0	0
JHO	-6	7	-6	5	2	9	11	6	2	0
MBU	15	40	26	19	12	15	13	9	2	0
RT	-38	-22	-22	-28	-28	-30	-30	-14	-1	0
WHS	10	10	10	-12	-7	-8	-5	-3	1	0
average	15	15	8	6	7	6	5	3	3	0
stdev	39	32	26	21	18	14	12	7	4	0

Table 4.3.3.2.5 compares the running average of four runs to that derived from six runs.

Table 4.3.3.2.5: Comparison between the running average of four runs to that of six runs.

Direction	Mean Peak Velocity (Deg/sec)	AVG of 10runs		AVG of 4 runs		AVG of 6runs	
		Mean error	Stdev error	Mean error	Stdev error	Mean error	Stdev error
TEM	320	0	0	4	16	6	19
NAS	329	0	0	6	21	6	14
UP	273	0	0	-2	17	-2	11
DOWN	274	0	0	4	29	0	16
UN	294	0	0	0	19	2	10
DT	272	0	0	9	31	5	16
UT	376	0	0	9	36	5	19
DN	250	0	0	15	24	7	11
			Average all directions	**6**	**24**	**4**	**15**

4.3.3.3 Amplitude:

The group mean of amplitudes obtained from the 20 observers in this age group for the 10 runs in all the eight directions is shown in Figure 4.3.3.3.1. All directions showed no significant difference ($p>0.05$) within the group between any of the ten runs (Table 4.3.3.3.1). This result indicates that there is no within trend arising from factors such as fatigue or changes in attention. The standard deviations indicate the overall intersubject variability. The mean and the standard deviations in each direction shown in Figure 4.3.3.3.1 are summarised in Table 4.3.3.3.2.

Table 4.3.3.3.1: Repeated measurements ANOVA results for the individual runs.

Directions	**ANOVA results** (Individual runs)
TEM	$F(9,90) = 0.33, p = 0.96$
NAS	$F(9,108) = 1.50, p = 0.16$
UP	$F(9,108) = 1.08, p = 0.39$
DOWN	$F(9,108) = 1.52, p = 0.15$
UN	$F(9.90) = 1.85, p = 0.07$
DT	$F(9,63) = 1.06, p = 0.41$
UT	$F(9,90) = 1.73, p = 0.09$
DN	$F(9,90) = 0.75, p = 0.66$

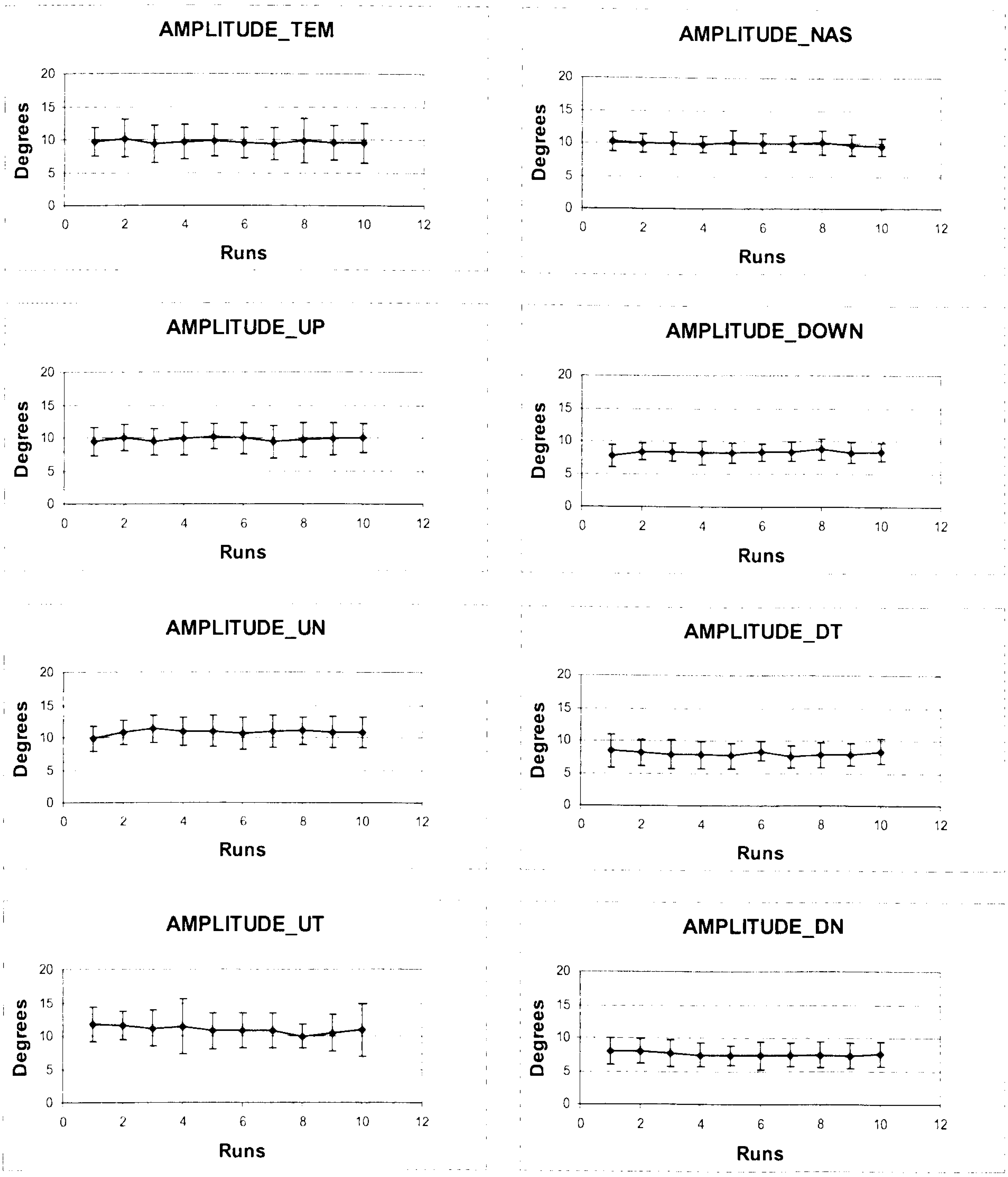


Figure 4.3.3.3.1: Each point on the graph represents the group mean obtain from the twenty individual subject measurements for amplitude. The error bars show standard deviations for each run.

Table 4.3.3.3.2: Group mean amplitudes, standard deviations and coefficient of variation for all individual 10 runs and 20 observers in each direction separately.

Directions	*Mean Amplitude (Degrees) (Group mean)*	*Stdev*	*Coefficient of variation %*
TEM	9.57	± 2.41	25
NAS	9.97	± 1.12	11
UP	9.81	± 1.96	20
DOWN	8.25	± 1.17	14
UN	10.79	± 1.95	18
DT	7.90	± 1.66	21
UT	10.84	± 2.60	24
DN	7.50	± 1.67	22
AVERAGE FOR ALL DIRECTIONS	**9.33**	**±1.82**	**19 %**

Figure 4.3.3.3.2 represents the running averages. A visual inspection of Figure 4.3.3.3.2 reveals an early progressive change in amplitude either at the level of the two run or at the average of only three runs in some directions after which the amplitude value appears stable.

An ANOVA (repeated measures) was applied and revealed a non-significant difference across the running averages in all directions (Table 4.3.3.3.3).

Table 4.3.3.3.3: Repeated measurements ANOVA results for the running averages.

Directions	**ANOVA results** (Running averages)
TEM	$F(9,152) = 0.78, p = 0.63$
NAS	$F(9,162) = 0.40, p = 0.93$
UP	$F(9,153) = 0.61, p = 0.78$
DOWN	$F(9,162) = 2.32, p = 0.13$
UN	$F(9,144) = 2.33, p = 0.14$
DT	$F(9,171) = 2.34, p = 0.12$
UT	$F(9,153) = 2.72, p = 0.09$
DN	$F(9,144) = 0.60, p = 0.80$

The results obtained from the statistical analysis (ANOVA) suggest that a representative value of amplitude might be achieved even from a single run. Table

4.3.3.3.4 shows the running average amplitude error for the up direction of each observer expressed as the amplitude error compared to the tenth one.

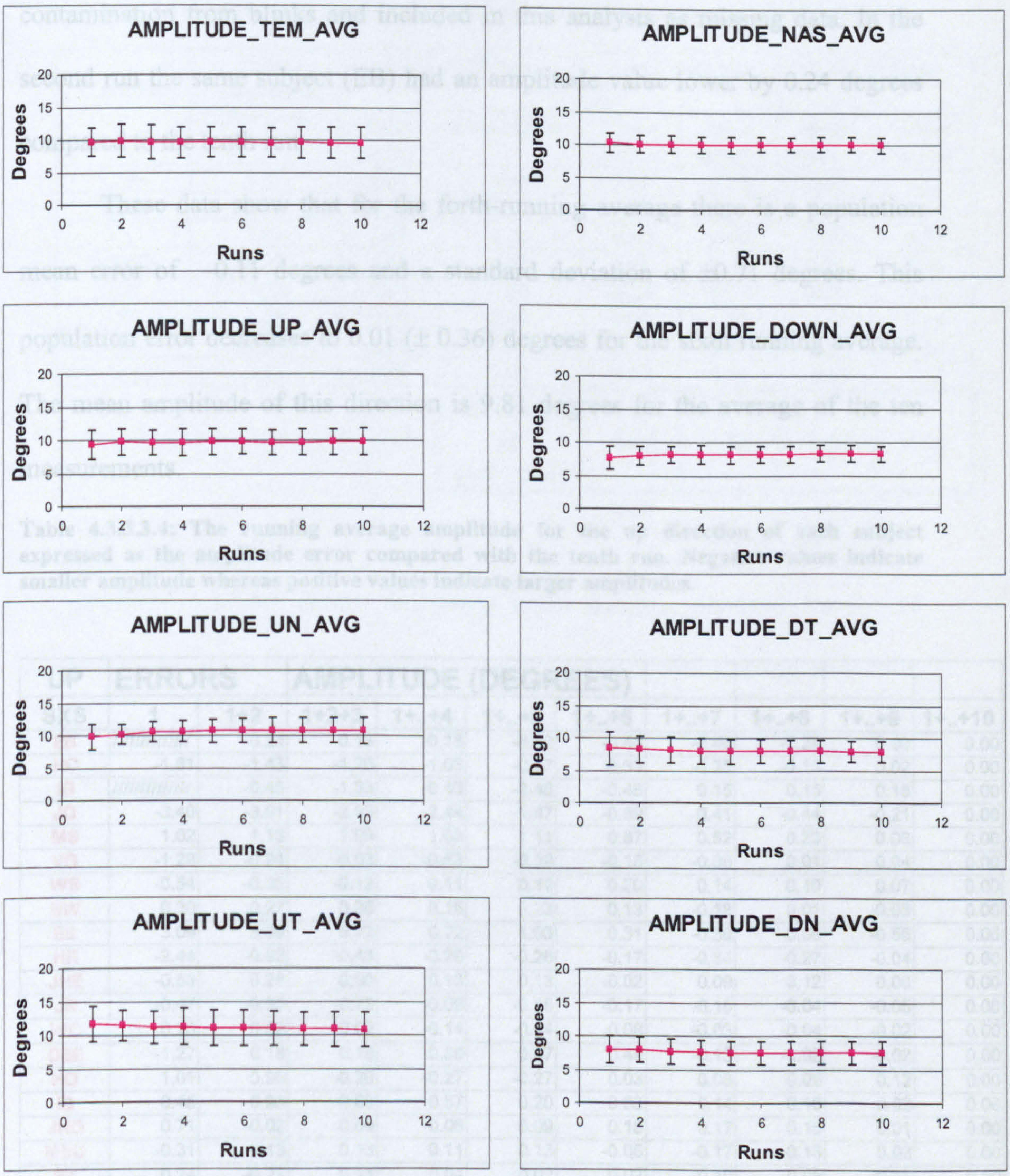


Figure 4.3.3.3.2: Running averages for amplitude. Each point on these graphs are the group mean obtaining from the twenty individual measurements for amplitude. Run number one is the group mean arising from 20 data values, run number two is the average of 40 and run number ten is the average of 200 data values. The error bars are standard deviations for each run.

Table 4.3.3.3.4 shows that the first measurement of our first subject (EB) was disregarded either due to effect of anticipation (negative latencies) and/or contamination from blinks and included in this analysis as missing data. In the second run the same subject (EB) had an amplitude value lower by 0.24 degrees compared to the tenth run.

These data show that for the forth-running average there is a population mean error of –0.11 degrees and a standard deviation of ±0.71 degrees. This population error decreases to 0.01 (± 0.36) degrees for the sixth running average. The mean amplitude of this direction is 9.81 degrees for the average of the ten measurements.

Table 4.3.3.3.4: The running average amplitude for the up direction of each subject expressed as the amplitude error compared with the tenth run. Negative values indicate smaller amplitude whereas positive values indicate larger amplitudes.

UP	ERRORS		AMPLITUDE (DEGREES)							
SXS	1	1+2	1+2+3	1+..+4	1+..+5	1+..+6	1+..+7	1+..+8	1+..+9	1+..+10
EB	/////////////	-0.24	0.13	-0.18	-0.52	-0.46	-0.46	-0.29	0.00	0.00
HC	-1.61	-1.43	-1.75	-1.03	-0.67	-0.33	-0.20	-0.19	0.02	0.00
IG	/////////////	-0.45	-1.33	-0.43	-0.48	-0.48	0.15	0.15	0.15	0.00
JO	-3.40	-3.01	-2.83	-2.44	-1.47	-0.69	-0.41	-0.44	-0.21	0.00
MS	1.02	1.13	1.09	1.03	1.11	0.87	0.52	0.23	0.08	0.00
VG	-1.29	-0.94	-0.93	-0.53	-0.39	-0.16	-0.06	0.01	0.04	0.00
WS	-0.54	-0.35	-0.12	0.11	0.12	0.20	0.14	0.10	0.07	0.00
BW	0.30	0.27	0.36	0.16	0.22	0.13	-0.18	0.01	-0.03	0.00
ES	3.09	3.09	0.72	0.72	1.03	0.31	-0.30	-0.66	-0.55	0.00
HR	-2.44	-0.92	-0.43	-0.29	-0.26	-0.17	-0.34	-0.27	-0.04	0.00
JHE	-0.53	0.26	0.00	0.13	0.13	-0.02	0.09	0.12	0.00	0.00
JR	-0.47	-0.35	-0.22	-0.09	-0.15	-0.17	-0.15	-0.04	-0.05	0.00
WC	0.20	0.02	0.02	-0.14	-0.04	0.08	-0.03	-0.04	-0.02	0.00
DBE	-1.27	0.18	0.18	0.36	0.47	0.49	-0.13	-0.02	-0.02	0.00
HO	1.01	0.96	-0.20	-0.27	-0.27	0.03	0.03	0.09	0.12	0.00
IB	0.45	0.93	0.89	0.57	0.20	0.33	0.14	0.16	0.02	0.00
JHO	0.71	-0.02	0.09	-0.06	0.09	0.15	0.17	0.15	0.01	0.00
MBU	-0.31	0.13	0.13	0.11	0.13	-0.05	-0.17	-0.13	0.03	0.00
RT	0.24	-0.27	0.11	0.04	0.02	0.02	-0.10	-0.08	-0.01	0.00
WHS	-0.88	0.55	0.68	-0.02	0.21	0.05	0.18	0.05	0.08	0.00
average	**-0.32**	**-0.02**	**-0.17**	**-0.11**	**-0.03**	**0.01**	**-0.06**	**-0.05**	**-0.02**	**0.00**
stdev	**1.45**	**1.18**	**0.93**	**0.71**	**0.57**	**0.36**	**0.24**	**0.22**	**0.15**	**0.00**

Table 4.3.3.3.5 compares the running average of amplitude in the elderly group based on four runs with those based on six runs.

Table 4.3.3.3.5: Comparison between the running average of four runs to that of six runs.

Direction	Mean Amplitude (Degrees)	AVG of 10runs		AVG of 4 runs		AVG of 6runs	
		Mean error	Stdev error	Mean error	Stdev error	Mean error	Stdev error
TEM	9.57	0.00	0.00	0.03	0.35	0.02	0.22
NAS	9.97	0.00	0.00	0.03	0.31	-0.01	0.24
UP	9.81	0.00	0.00	-0.06	0.40	-0.02	0.27
DOWN	8.25	0.00	0.00	0.03	0.40	0.01	0.25
UN	10.79	0.00	0.00	-0.14	0.52	-0.04	0.26
DT	7.90	0.00	0.00	0.05	0.77	0.04	0.46
UT	10.84	0.00	0.00	-0.05	0.37	-0.04	0.25
DN	7.50	0.00	0.00	-0.04	0.54	-0.01	0.32
			Average all directions	**-0.02**	**0.46**	**-0.01**	**0.28**

4.3.3.4 Duration:

Figure 4.3.3.4.1 shows the group mean duration obtained for the 20 subjects in the group of the elderly for the ten individual runs in all directions. Table 4.3.3.4.1 shows a summary of the analysis of variance that was applied for each direction respectively.

All directions showed no significant difference ($p>0.05$) within the group between any of the ten runs. Therefore appears to be no within trend arising from factors such as fatigue, learning or changes in attention

Table 4.3.3.4.1: Repeated measures ANOVA results for the individual runs.

Directions	ANOVA results (Individual runs)
TEM	$F(9,90) = 0.53, p = 0.85$
NAS	$F(9,108) = 1.42, p = 0.19$
UP	$F(9,108) = 1.47, p = 0.17$
DOWN	$F(9,108) = 1.42, p = 0.19$
UN	$F(9,90) = 1.06, p = 0.40$
DT	$F(9.63) = 0.78, p = 0.64$
UT	$F(9,90) = 0.98, p = 0.46$
DN	$F(9,90) = 1.81, p = 0.08$

Table 4.3.3.4.2 shows a summary of the mean durations and the standard deviations in each direction shown in Figure 4.3.3.4.1. This age group have shown the highest intersubject variability in several directions.

Table 4.3.3.4.2: Group mean durations, standard deviations and coefficient of variation for all individual 10 runs and 20 observers in each direction separately.

Directions	*Mean Duration (msecs) (Group mean)*	*Stdev*	*Coefficient of variation %*
TEM	53	± 11	21
NAS	56	± 19	34
UP	82	± 31	38
DOWN	64	± 23	36
UN	89	± 36	40
DT	53	± 16	30
UT	64	± 24	37
DN	56	± 17	31
AVERAGE FOR ALL DIRECTIONS	**65**	**±22**	**33 %**

Figure 4.3.3.4.2 represents the running averages. A visual inspection of Figure 4.3.3.4.2 reveals early stabilisation of duration. An analysis of variance revealed a non-significant difference across the running averages in all directions (Table 4.3.3.4.3), which suggests that even one measurement may give a representative duration. This result is probably not supported by the graphs in Figure 4.3.3.4.2 in all directions.

Table 4.3.3.4.3: Repeated measurements ANOVA results for the running averages.

Directions	**ANOVA results** (Running averages)
TEM	$F(9,153) = 0.56, p = 0.83$
NAS	$F(9,162) = 1.65, p = 0.11$
UP	$F(9,153) = 0.77, p = 0.64$
DOWN	$F(9,162) = 1.15, p = 0.33$
UN	$F(9,144) = 2.40, p = 0.12$
DT	$F(9,171) = 0.49, p = 0.88$
UT	$F(9,153) = 4.70, p = 0.52$
DN	$F(9,144) = 3.45, p = 0.07$

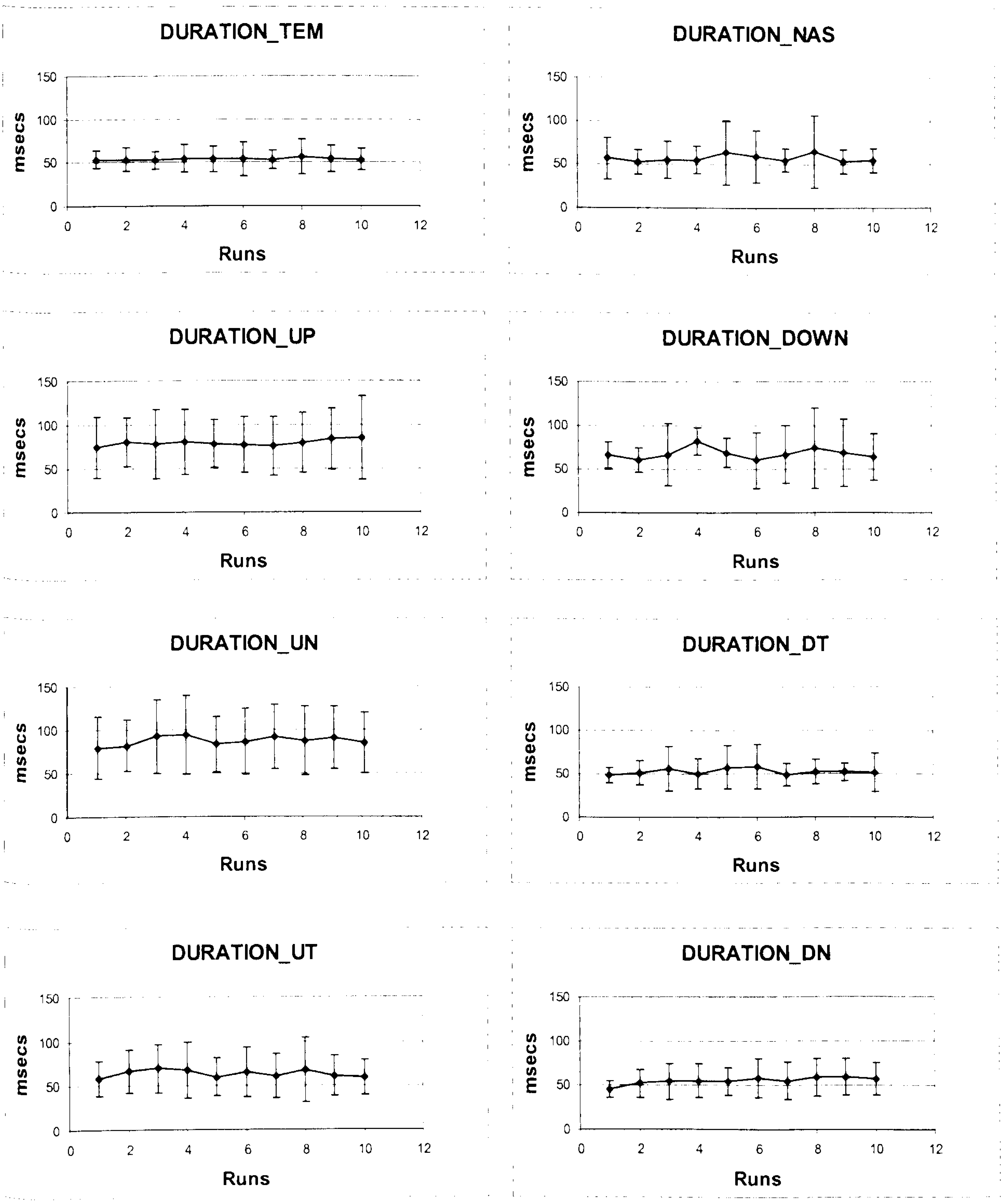


Figure 4.3.3.4.1: Each point on the graph represents the group mean obtain from the twenty individual subject measurements for duration. The error bars are ±1 standard deviation

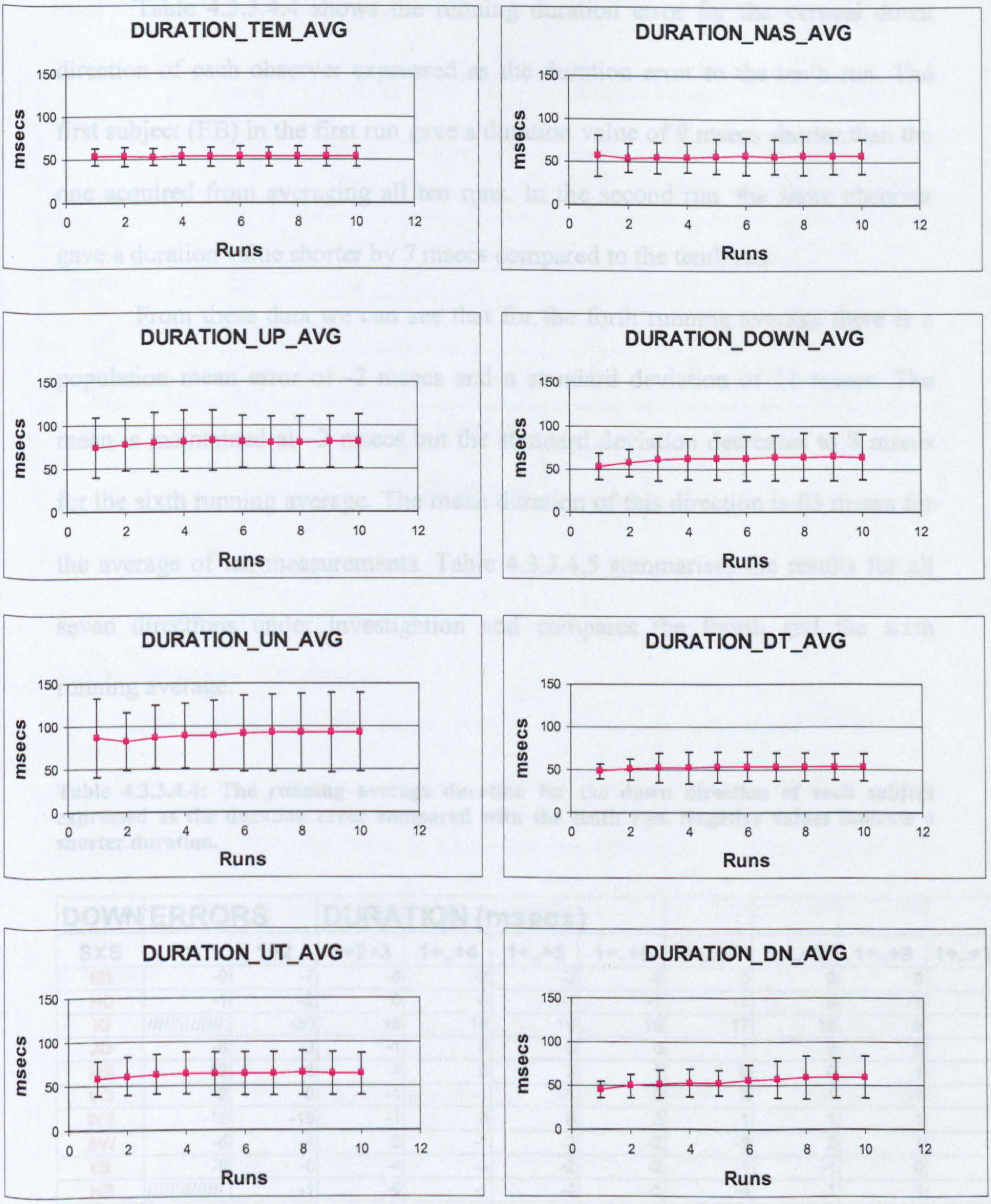


Figure 4.3.3.4.2: Running averages for duration. Each point on these graphs are the group mean obtaining from the twenty individual measurements for duration. Run number one is the group mean arising from 20 data values, run number two is the average of 40 and run number ten is the average of 200 data values. The error bars show standard deviation.

Table 4.3.3.4.4 shows the running duration error for the vertical down direction of each observer expressed as the duration error to the tenth run. The first subject (EB) in the first run gave a duration value of 9 msecs shorter than the one acquired from averaging all ten runs. In the second run, the same observer gave a duration value shorter by 7 msecs compared to the tenth run.

From these data we can see that for the forth running average there is a population mean error of -2 msecs and a standard deviation of 11 msecs. The mean is maintained at –2 msecs but the standard deviation decreases to 8 msecs for the sixth running average. The mean duration of this direction is 63 msecs for the average of ten measurements. Table 4.3.3.4.5 summarises the results for all seven directions under investigation and compares the fourth and the sixth running average.

Table 4.3.3.4.4: The running average duration for the down direction of each subject expressed as the duration error compared with the tenth run. Negative values indicate a shorter duration.

DOWN	ERRORS		DURATION (msecs)							
SXS	**1**	**1+2**	**1+2+3**	**1+..+4**	**1+..+5**	**1+..+6**	**1+..+7**	**1+..+8**	**1+..+9**	**1+..+10**
EB	-9	-7	-6	-2	-2	-3	0	0	0	0
HC	-1	-2	0	0	-1	-1	-1	0	-1	0
IG	//////////////	-30	16	16	16	16	17	16	8	0
JO	-8	-3	-1	0	0	0	1	0	0	0
MS	13	8	4	5	3	1	0	0	1	0
VG	-2	0	-1	-1	-1	0	0	-1	-1	0
WS	-16	-16	-1	0	6	3	1	1	1	0
BW	-6	-4	-2	-1	-2	-2	-2	2	1	0
ES	-9	-6	-4	-3	-2	-2	-1	-1	0	0
HR	//////////////	-1	-6	-1	-4	-5	-4	-1	1	0
JHE	-1	-1	-1	3	2	-1	-1	-1	-1	0
JR	-11	-7	-2	-1	1	-1	-2	-1	-1	0
WC	-11	-6	-5	-3	-2	-2	-1	-1	0	0
DBE	-2	2	-2	-4	-2	-3	-3	-4	-3	0
HO	-6	-7	1	1	0	1	-1	1	0	0
IB	-11	1	-2	-3	-2	-2	1	0	0	0
JHO	12	6	3	6	4	2	2	2	2	0
MBU	-12	-2	-2	-5	0	0	0	1	0	0
RT	-51	-57	-48	-45	-47	-31	-23	-10	-3	0
WHS	1	-4	-2	-6	-3	-3	-3	-3	1	0
avg	**-7**	**-7**	**-3**	**-2**	**-2**	**-2**	**-1**	**0**	**0**	**0**
stdev	**13**	**14**	**12**	**11**	**11**	**8**	**7**	**5**	**2**	**0**

Table 4.3.3.4.5: Comparison between the running average of four runs to that of six runs.

Direction	Mean Duration (msecs)	AVG of 10runs		AVG of 4 runs		AVG of 6runs	
		Mean error	Stdev error	Mean error	Stdev error	Mean error	Stdev error
TEM	53	0	0	0	4	0	2
NAS	56	0	0	-2	3	0	4
UP	82	0	0	0	13	0	7
DOWN	63	0	0	-1	6	-1	6
UN	89	0	0	-2	8	-2	5
DT	53	0	0	-1	6	1	3
UT	64	0	0	1	5	1	4
DN	55	0	0	-3	2	-2	2
			Average all directions	-1	6	0	4

4.4 Discussion

4.4.1 Primary Analysis

The aim of this procedure was to establish the minimum number of saccades required in one session without compromising precision with consideration of the time taken to make the measurements. A good clinical test must give a representative result that is repeatable in the shortest measurement time possible.

The same methodology was applied for every age group and every direction in all the saccadic parameters under investigation (latency, peak velocity, amplitude and duration). Comparisons will be made in order to assess the effect of age and direction (if any) upon those saccadic parameters in other Chapters of this thesis.

An overall review of our results indicates that the saccadic parameters (latency, peak velocity, amplitude and duration) in all three age group appear to show no sequential trends over a ten measurement recording session. This may be due to the fact that short-breaks were given between each session in order to minimise the effects of fatigue. In addition, instructions were also given to our observers prior to the start of the recording sessions in order to minimise trends arising from factors such as learning or changes in attention.

The larger intersubject variability in the elderly group compared to the young and middle-aged groups suggests an effect of ageing on saccadic eye movements. This is an aspect that will be investigated in depth in Chapter five. The effect of direction on the saccadic parameters will also be investigated in Chapters five, six, seven and eight.

The coefficient of variation was also used to give an overall picture of intersubject variability. Table 4.4.1.1 shows a summary of the mean coefficients of variation from all directions in each saccadic parameter and each age group respectively. These values show that saccadic latency gives the least variable measurements in all age groups. This low intersubject variation may indicate a parameter that will be particularly useful to discriminate normal from abnormal responses in all age groups. In addition, saccadic amplitude might be considered to be informative since it does not show a high variability but further investigation with different ranges of amplitude is necessary. The average coefficient of variation suggests that saccadic duration may not be as useful as a diagnostic tool for the elderly observers but it may give some information in the young and middle age groups. The most variable parameter is saccadic peak velocity; therefore its clinical suitability is less impressive. These results agree with those reported by Van Dongen, *et al* (1991). In that study an infrared technique was used (where they used the same eye tracker, IRIS 6500, as this study), they suggested that saccadic latency was the saccadic parameter that could identify treatment effect more successfully in patients with multiple sclerosis than amplitude and peak velocity. The sensitivity of amplitude in detecting treatment improvement was half of that obtained by latency whereas peak velocity showed no diagnostic promise.

Table 4.4.1.1: Summary values for average, standard deviation and mean coefficients of variation from all 8 directions in all saccadic parameters and age groups.

LATENCY (msecs)	***Average***	***Stdev***	***Coefficient of variation***
GROUP I (20-39 years)	242	(±30)	13 %
GROUP II (40-59 years)	255	(±30)	12 %
GROUP III (60-89 years)	289	(±43)	15 %
PEAK VELOCITY (deg/sec)	***Average***	***Stdev***	***Coefficient of variation***
GROUP I (20-39 years)	316	(±84)	26 %
GROUP II (40-59 years)	331	(±93)	28 %
GROUP III (60-89 years)	299	(±89)	30 %
AMPLITUDE (degrees)	***Average***	***Stdev***	***Coefficient of variation***
GROUP I (20-39 years)	9.25	(±1.84)	20 %
GROUP II (40-59 years)	9.09	(±1.82)	21 %
GROUP III (60-89 years)	9.33	(±1.82)	19 %
DURATION (msecs)	***Average***	***Stdev***	***Coefficient of variation***
GROUP I (20-39 years)	55	(±12)	21 %
GROUP II (40-59 years)	50	(±11)	21 %
GROUP III (60-89 years)	65	(±22)	33 %

4.4.1.1 LATENCY

Visual inspection of the running average graphs and the ANOVA suggest that a representative value of saccadic latency may be obtained even after a single measurement in some of the directions and age groups under investigation. However, there were some occasions that the merging of three or four runs was found necessary. Moreover, the results attained from the repeated measurements ANOVA in the young age group (I) indicated that the merging of four runs was required in the oblique directions with an upward component (UN, UT). Similarly, in the middle-aged group (II) the same number of repeated measurements was necessary in order to acquire a representative value of saccadic latency in the nasal (NAS) direction whereas the merging of only three runs was needed in the temporal (TEM) and up (UP) directions. The data set of the elderly group showed the highest intersubject variability and revealed that the merging of four runs was necessary in all the directions under investigation.

4.4.1.2 PEAK VELOCITY

The ANOVA suggested that a representative value of peak velocity might be obtained even after a single measurement in all directions for the young and elderly age group. In addition, the results obtained for the middle-group showed that a representative value of peak velocity was attained with a single recording in most directions except the down –nasal (DN) where the merging of two runs was needed.

4.4.1.3 AMPLITUDE

A visual inspection of the running averages (Figure 4.3.1.3.2 / 4.3.2.3.2 / 4.3.3.3.2) of each age group and the ANOVA revealed that a representative value of saccadic amplitude could be obtained even after a single measurement in all directions under investigation. This set of data indicated two additional factors. Firstly, the young age group showed a higher intersubject variability in the up nasal (UN) direction when compared to the other directions. This result was not identified in the other two age groups, therefore no specific pattern could be recognised.

Secondly, all age groups showed that there might be a tendency to undershoot (have lower amplitudes than 10°) in the directions with a downward element (DOWN, DT, DN) compared to the others. This result may be attributed to the fact that individuals tend to move their heads more that their eyes when they wish to look down. This finding should be considered in Chapter five that deals with the influence of direction on several saccadic parameters.

4.4.1.4 DURATION

Visual inspection of the running average graphs and the ANOVA suggest that a representative value of saccadic duration may be obtained even after a single measurement in the majority of directions and age groups under investigation apart from a single condition. The results attained from the analysis of variance in the young age group (I) indicated that the merging of four runs was required only in the nasal direction.

This set of data also revealed that all age groups had a higher intersubject variability in all directions with an upward component (UP, UN and UT) compared to the other directions.

4.4.2 Secondary Analysis

If the merging of all ten runs is regarded as the best estimate of a saccadic eye movement, and the other running averages are expressed as an error above or below this value, then the statistical analysis indicate that the accuracy of these parameters improve as the number of runs increases. Table 4.4.2.1 shows a summary of the average error from all eight directions for four runs and six runs based on the assumption that the ten run average gives the true (error free) value, in all the saccadic parameters and age groups. These values show that the merging of six runs will give us a smaller mean and standard deviation of error in all age groups. There are some occasions were the mean error is the same or similar between the forth and sixth running average but their standard deviations are always smaller in the running average of six runs.

These errors expressed as a percentage of the mean value for each parameter indicate that the average of four runs produces a mean error, which is less than 5% of the average measurement in all cases (Table 4.4.2.2). It was decided to adopt the 5% level as the criterion for an acceptable level of error. This results in acceptance of a four run running average for measurement. This is supported by the primary ANOVA analysis of the running averages for the different age groups.

Table 4.4.2.2: Summary table that shows the average mean error from all 8 directions expressed as a percentage of the mean measurements of each saccadic parameter and each age group for the four run running average.

MEAN ERROR expressed as a % of the measurement			
	20- 39 years Group I	40- 59 years Group II	60- 80 years Group III
LATENCY	3 %	3 %	1 %
PEAK VELOCITY	2 %	1.8 %	2 %
AMPLITUDE	0.2 %	0.3 %	0.2 %
DURATION	1.8 %	2 %	1.6 %

Thus we concluded that the merging of four runs would provide a good compromise by giving a representative value in each of the saccadic metrics (latency, peak, velocity, amplitude and duration) that is achieved in a reasonable time.

Table 4.4.2.1: Summary table that shows the average from all 8 direction population mean error and standard deviation after averaging four runs and six runs when compare to the tenth one, which is assumed to be the most precise, in all age groups and for all saccadic parameters respectively.

Errors												
	Group I (20-39years)				Group II (40-59years)				Group III (60-80years)			
	Average 4 runs		Average 6 runs		Average 4 runs		Average 6 runs		Average 4 runs		Average 6 runs	
	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev
Latency *(msecs)*	7	(±16)	3	(±11)	7	(±18)	2	(±12)	2	(±25)	-1	(±15)
Peak Velocity *(Deg/secs)*	6	(±17)	4	(±11)	6	(±22)	4	(±12)	6	(±24)	4	(±15)
Amplitude *(Degrees)*	-0.02	(±0.46)	-0.01	(±0.28)	0.03	(±0.47)	0.03	(±0.32)	-0.02	(±0.46)	-0.01	(±0.28)
Duration *(msecs)*	-1	(±3)	-1	(±2)	-1	(±4)	-1	(±2)	-1	(±6)	0	(±4)

4.5 Test / Retest Variability

4.5.1 Introduction

Quantitative recording and analysis of saccadic eye movements is becoming a valuable clinical tool in a number of neurological (Van Dongen, *et al.* 1991; Rottach, *et al.*1996; Walker and Findlay, 1996; Flipse, *et al.* 1997; Barton, 1998; Harvey, *et al.* 2002; Serra, *et al.* 2003) as well as ophthalmological disorders (Feldon and Unsold, 1982; Mauri, *et al.* 1984; Mourits, *et al.* 1994; Wouters, *et al.* 1998; Schworm *et al.* 2000).

There are several aspects that determine the value of a specific recording technique in a clinical environment. Those include precision of measurement and test-rest variability. There are several studies that have investigated this latter parameter (Van Dongen, *et al.* 1991; Versino, *et al.* 1992; Wilson, *et al.* 1993).

Van Dongen, *et al.* (1991) using an infrared scleral reflection technique (IRIS), demonstrated that eye movements could provide a reliable follow-up tool for the assessment of the central nervous system. They recorded horizontal saccadic and smooth pursuit eye movements in patients with established multiple sclerosis on two occasions and in two different groups. The time interval was five days.

Versino, *et al.* (1992) used electrooculography and recorded binocular saccadic eye movements in three recording sessions. The time interval between the first two sessions was one week whereas the third recording took place after a period of time of four to seven months. They also suggested that the quantitative evaluation of saccadic eye movements is reliable and could be used in longitudinal studies. They also reported that reliability would increase when less noisy recording techniques like infrared reflection and magnetic search coil methods were used.

In another study, where an electrooculography was used, Wilson, *et al.* (1993) recorded horizontal saccadic eye movements in 11 observers on four different recording occasions. The time interval was a few days to several months. They suggested that electrooculography provides a reliable recording method of obtaining saccadic eye movement data.

Previously, we deduced that the average of four repeated measurements would provide a representative result of saccadic latency, peak velocity, amplitude and duration in all eight directions and for the different age groups. The aim of this section of the study is to investigate the repeatability of our non-invasive eye movement measurement technique. If a clinical test has poor repeatability then its usefulness is limited.

4.5.2 Methods

The sixty visually normal volunteers participated in this study were divided in three age groups [Group I: number of observers 20 (11 Female), range 20-39 (median 25.5); Group II: number of observers 20 (10 Female), range 40-59 (median 40); Group III: number of observers 20 (11Female), range 60-89 (median 69.5)]. The same methodology (stimulus, eye movement monitoring apparatus, recording system, experimental procedure) was used in this study as described previously in section 4.2. The experimental procedure was repeated at a second recording occasion for all 60 observers. The time interval between the two occasions was one week. This was believed to be appropriate because it was a long enough interval to avoid any type of bias in our retest data due to memory but was short enough to avoid changes in our observers' true status.

4.5.3 Results

For each observer in the different age group, we obtained individual values for each saccadic parameter (latency, duration, peak velocity and amplitude) and calculated the average and standard deviation from four measurements in all the 8 directions under investigation and in the two sessions (test/retest) respectively.

Table 4.5.3.1 shows the mean latency of each young observer obtained after the merging of four runs in the temporal direction for the test and retest trial. The third column represents the difference between those two trials. At the bottom of each column, there is the average, standard deviation and the coefficient of repeatability for the young group in this specific direction for saccadic latency. These values were calculated for all age groups and all the saccadic parameters in the eight directions under investigation respectively.

Table 4.5.3.1: The average latencies for the temporal direction of each observer in the test/retest trials with intra-individual difference between the paired evaluations.

GROUP I (20 - 39 years)				
TEMPORAL				
Pxs	LATENCY (m secs)			
	TEST	RETEST	DIFF	MEAN
CH	213	207	-6	210
EL	251	255	5	253
HK	253	283	30	268
PM	203	209	6	206
SN	230	238	9	234
AR	232	227	-6	229
DC	215	222	7	219
EG	321	324	3	322
MB	225	240	15	232
PK	283	284	1	284
AB	241	218	-23	229
EP	240	246	6	243
IU	222	200	-22	211
RS	242	232	-10	237
AS	202	182	-20	192
IM	227	205	-22	216
AN	223	198	-25	210
MM	275	275	0	275
AM	216	210	-6	213
VJ	261	268	7	264
AVG	**239**	**236**	**-3**	**237**
STDEV	**29**	**36**	**14**	**32**
COEF OF REPEATABILITY			**28**	

The coefficient of repeatability ($1.96 \times STDEV_{Difference}$) shows the relationship between the two measurements. Thus in the temporal direction we are 95% confident that the saccadic latency of the second measurement is likely to be within ± 28 milliseconds of the first measurement. Bland and Altman (1986) suggested that if a measurement shows a change greater than the coefficient of repeatability then this can be considered as clinically significant.

Table 4.5.3.2 shows the mean differences between test and retest as well as the coefficients of repeatability for each direction respectively in all the age groups for the saccadic latency.

The mean coefficient of repeatability shows a slight increase with aging. This result indicates that the saccadic measurements obtained from the middle-aged (group II) and elderly (group III) are slightly less repeatable when compare to the young group (I).

In a correctly controlled repeatability study, the mean of the differences (the bias) should be either zero or not significantly different from zero. From these data we can see that the population mean difference is close to zero. Therefore, the latency measurement appears to be repeatable.

A graphical representation of this table is shown in Figure 4.5.3.1, which represents the plot of differences between the two trials against their mean in all the age groups [(a) Group I (20-39 years), (b) Group II (40-59 years) and (c) Group III (60-89 years)] for the saccadic latency. Each data point represents the difference between the two trials of each observer and each symbol shows the different direction under investigation.

Table 4.5.3.2: A summary of the mean differences and the coefficient of repeatability in saccadic latency for all the different age groups (I, II, III) in all the directions.

LATENCY (msecs)						
	20-39 years (Group I)		40-59 years (Group II)		60-80 years (Group III)	
Directions	Mean difference (Test/retest)	Coefficient of repeatability	Mean difference (Test/retest)	Coefficient of repeatability	Mean difference (Test/retest)	Coefficient of repeatability
TEM	-3	28	3	42	-1	49
NAS	-3	22	7	41	5	42
UP	1	21	4	41	5	44
DOWN	3	23	2	39	5	58
UN	1	28	4	39	6	39
DT	-1	24	10	36	-8	55
UT	-2	26	4	45	4	30
DN	-2	31	-1	37	6	60
AVERAGE	-1	25	4	40	3	48

The black dotted line represents the bias of the measurements whereas the red dotted lines represent the estimate of error. A visual inspection of the plots in Figure 4.5.3.1 reveals that the bias (black dotted line) of our measurements is close to zero for all age groups in the saccadic latency, thus this set of data is correctly controlled for repeatability. The error represented by the red dotted lines is derived as in table 4.5.3.2.

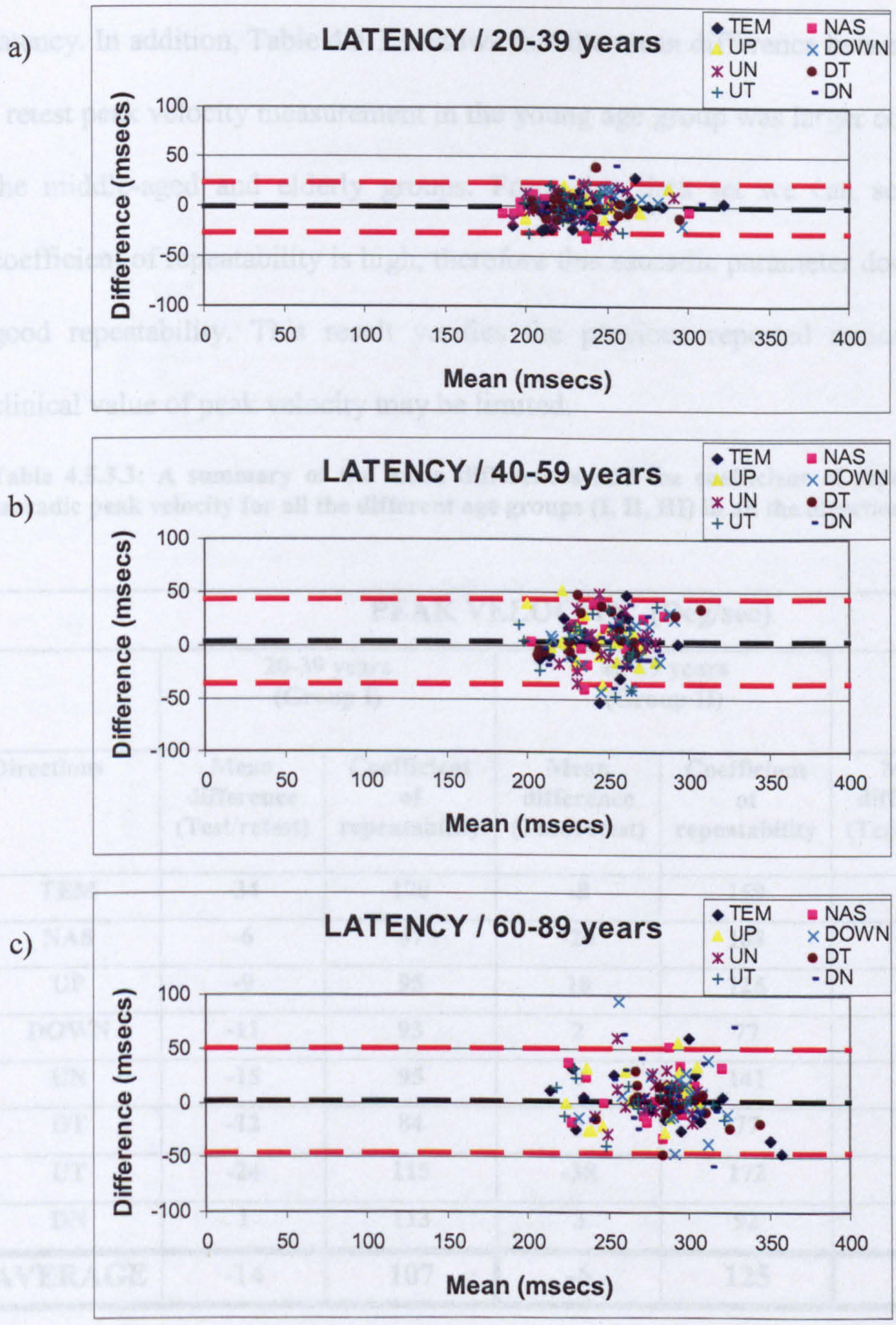


Figure 4.5.3.1: These plots correspond to (a) young group (Group I: age range 20-39 years), (b) middle aged group (Group I: age range 40-59 years) and (c) elderly group (Group III: age range 60-89 years) for saccadic latency. The x-axis represents the mean between the two trials (test/retest) whereas the y-axis represents their differences. Each symbol characterises the different directions and each point represents a single individual. The black dotted lines represent the bias of the measurements whereas the red dotted lines represent the estimate of error (±1.96*STDEV$_{DIFF}$).

We examined the data set of peak velocity in the same way as above (Table 4.5.3.3). This table shows the same increase in the mean coefficient of repeatability between the age groups as mentioned previously for the saccadic latency. In addition, Table 4.5.3.3 shows that the mean difference between the test / retest peak velocity measurement in the young age group was larger compared to the middle-aged and elderly groups. From this data set we can see that the coefficient of repeatability is high, therefore this saccadic parameter does not give good repeatability. This result verifies the previous reported notion that the clinical value of peak velocity may be limited.

Table 4.5.3.3: A summary of the mean differences and the coefficient of repeatability in saccadic peak velocity for all the different age groups (I, II, III) in all the direction.

PEAK VELOCITY (Deg/sec)						
	20-39 years (Group I)		40-59 years (Group II)		60-80 years (Group III)	
Directions	Mean difference (Test/retest)	Coefficient of repeatability	Mean difference (Test/retest)	Coefficient of repeatability	Mean difference (Test/retest)	Coefficient of repeatability
TEM	-34	170	-8	159	57	119
NAS	-6	67	-26	108	-23	89
UP	-9	95	18	125	-23	99
DOWN	-11	93	2	77	0	161
UN	-15	95	0	141	4	170
DT	-12	84	1	77	-14	122
UT	-24	115	-38	172	-10	202
DN	1	113	3	92	1	63
AVERAGE	**-14**	**107**	**-6**	**125**	**-1**	**140**

Figure 4.5.3.2 is a graphical representation of Table 4.5.3.3 that shows the plot of differences between the two trials against their mean in all the age groups [(a) Group I (20-39 years), (b) Group II (40-59 years) and (c) Group III (60-89 years)] for the saccadic peak velocity. Each data point represents the difference between the two trials of each observer and each symbol shows the different

direction under investigation. The black dotted line represents the bias of the measurements whereas the red dotted lines represent the estimate of error.

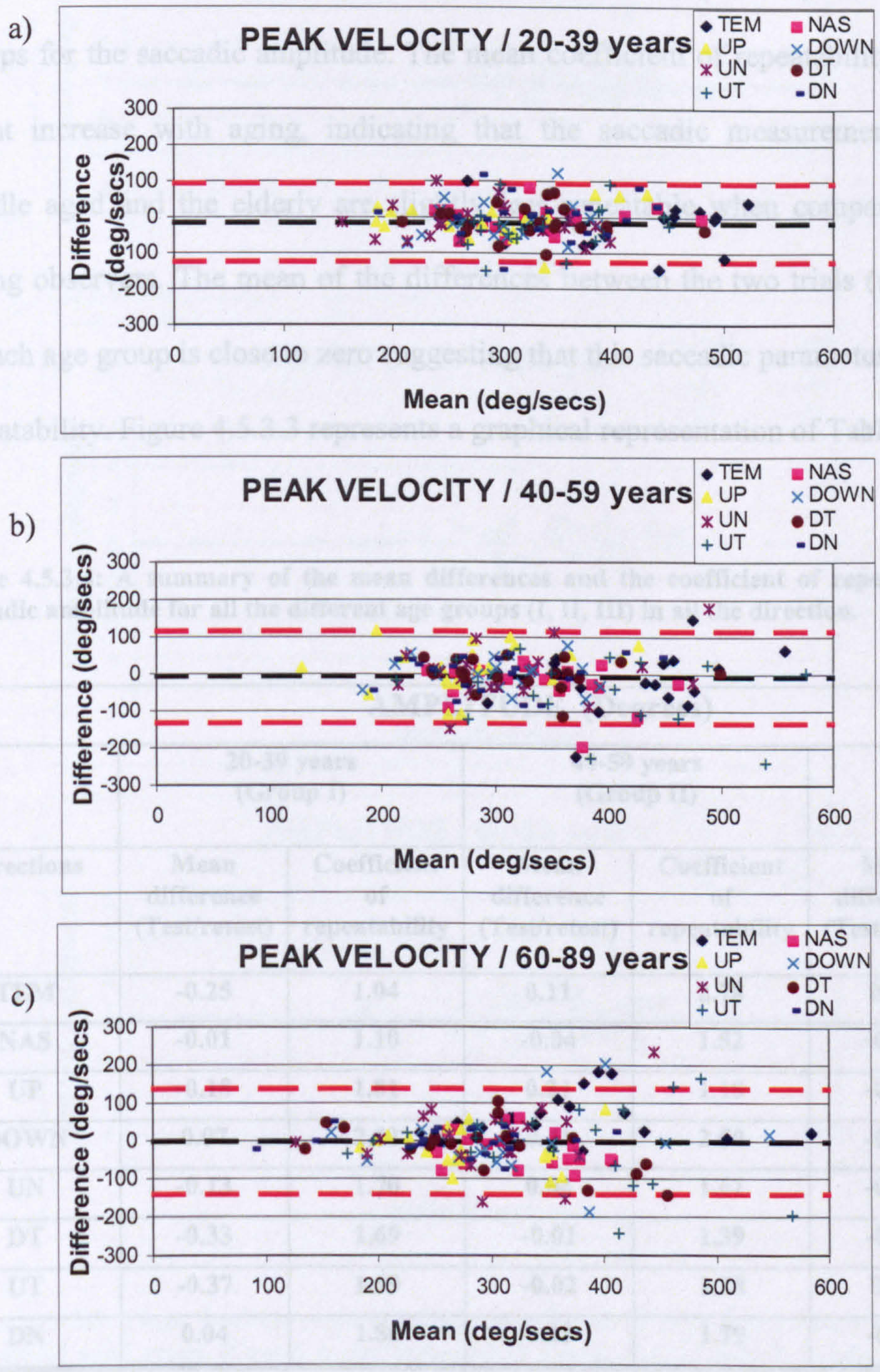


Figure 4.5.3.2: These plots correspond to (a) young group (Group I: age range 20-39 years), (b) middle aged group (Group I: age range 40-59 years) and (c) elderly group (Group III: age range 60-89 years) for saccadic peak velocity. The x-axis represents the mean between the two trials (test/retest) whereas the y-axis represents their differences. Each symbol characterises the different directions and each point represents a single individual. The black dotted lines represent the bias of the measurements whereas the red dotted lines represent the estimate of error (±1.96*STDEV$_{DIFF}$).

Table 4.5.3.4 shows the mean differences between test and retest as well as the coefficients of repeatability for each direction respectively in all the age groups for the saccadic amplitude. The mean coefficient of repeatability shows a slight increase with aging, indicating that the saccadic measurements in the middle aged and the elderly are slightly less repeatable when compared to the young observers. The mean of the differences between the two trials (test/retest) in each age group is close to zero suggesting that this saccadic parameter has good repeatability. Figure 4.5.3.3 represents a graphical representation of Table 4.5.3.4.

Table 4.5.3.4: A summary of the mean differences and the coefficient of repeatability in saccadic amplitude for all the different age groups (I, II, III) in all the direction.

AMPLITUDE (Degrees)						
	20-39 years (Group I)		40-59 years (Group II)		60-80 years (Group III)	
Directions	Mean difference (Test/retest)	Coefficient of repeatability	Mean difference (Test/retest)	Coefficient of repeatability	Mean difference (Test/retest)	Coefficient of repeatability
TEM	-0.25	1.04	0.11	2.78	0.86	2.16
NAS	-0.01	1.10	-0.04	1.52	-0.39	1.51
UP	-0.18	1.81	0.21	1.18	-0.40	2.66
DOWN	0.07	2.22	0.41	2.50	-0.16	2.04
UN	-0.13	1.70	0.04	1.61	-0.20	1.63
DT	-0.33	1.69	-0.01	1.39	-0.08	2.02
UT	-0.37	1.59	-0.02	1.28	0.27	2.39
DN	0.04	1.86	0.25	1.79	-0.22	1.90
AVERAGE	-0.15	1.66	0.12	1.82	-0.04	2.17

a) b) c)

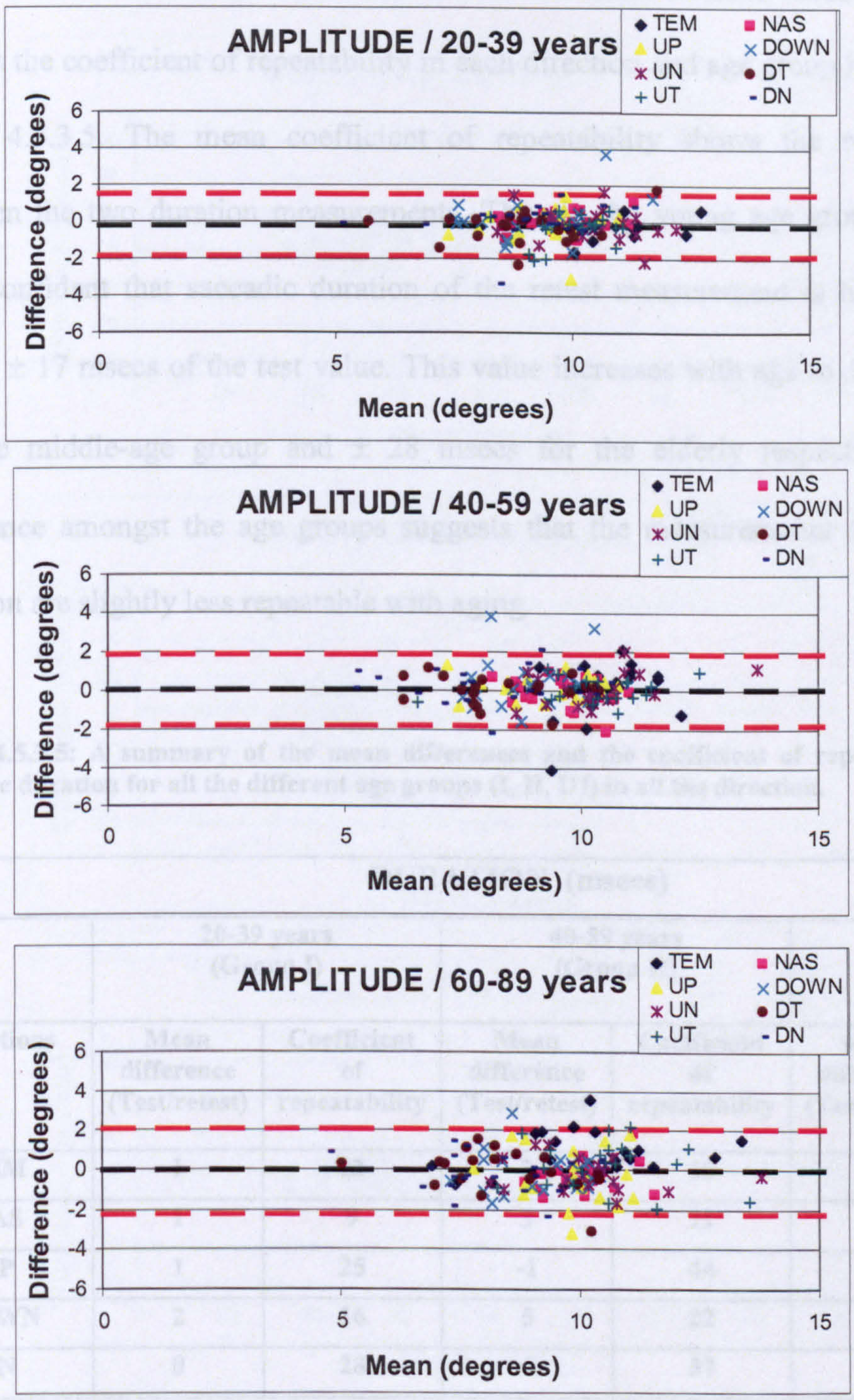


Figure 4.5.3.3: These plots correspond to (a) young group (Group I: age range 20-39 years), (b) middle aged group (Group I: age range 40-59 years) and (c) elderly group (Group III: age range 60-89 years) for saccadic amplitude. The x-axis represents the mean between the two trials (test/retest) whereas the y-axis represents their differences. Each symbol characterises the different directions and each point represents a single individual. The black dotted lines represent the bias of the measurements whereas the red dotted lines represent the estimate of error (±1.96*STDEV$_{DIFF}$).

The mean difference between the test and retest duration measurement as well as the coefficient of repeatability in each direction and age group is shown in Table 4.5.3.5. The mean coefficient of repeatability shows the relationship between the two duration measurements. Thus in the young age group, we are 95% confident that saccadic duration of the retest measurement is likely to be within ± 17 msecs of the test value. This value increases with age to ± 26 msecs for the middle-age group and ± 28 msecs for the elderly respectively. The difference amongst the age groups suggests that the measurements of saccadic duration are slightly less repeatable with aging.

Table 4.5.3.5: A summary of the mean differences and the coefficient of repeatability in saccadic duration for all the different age groups (I, II, III) in all the direction.

DURATION (msecs)						
	20-39 years (Group I)		40-59 years (Group II)		60-80 years (Group III)	
Directions	Mean difference (Test/retest)	Coefficient of repeatability	Mean difference (Test/retest)	Coefficient of repeatability	Mean difference (Test/retest)	Coefficient of repeatability
TEM	1	12	1	16	0	12
NAS	1	9	3	11	4	10
UP	1	25	-1	44	1	34
DOWN	2	16	5	22	2	24
UN	0	28	6	37	8	47
DT	0	11	4	13	3	13
UT	3	20	9	23	1	39
DN	2	8	3	20	-3	18
AVERAGE	**1**	**17**	**4**	**26**	**2**	**28**

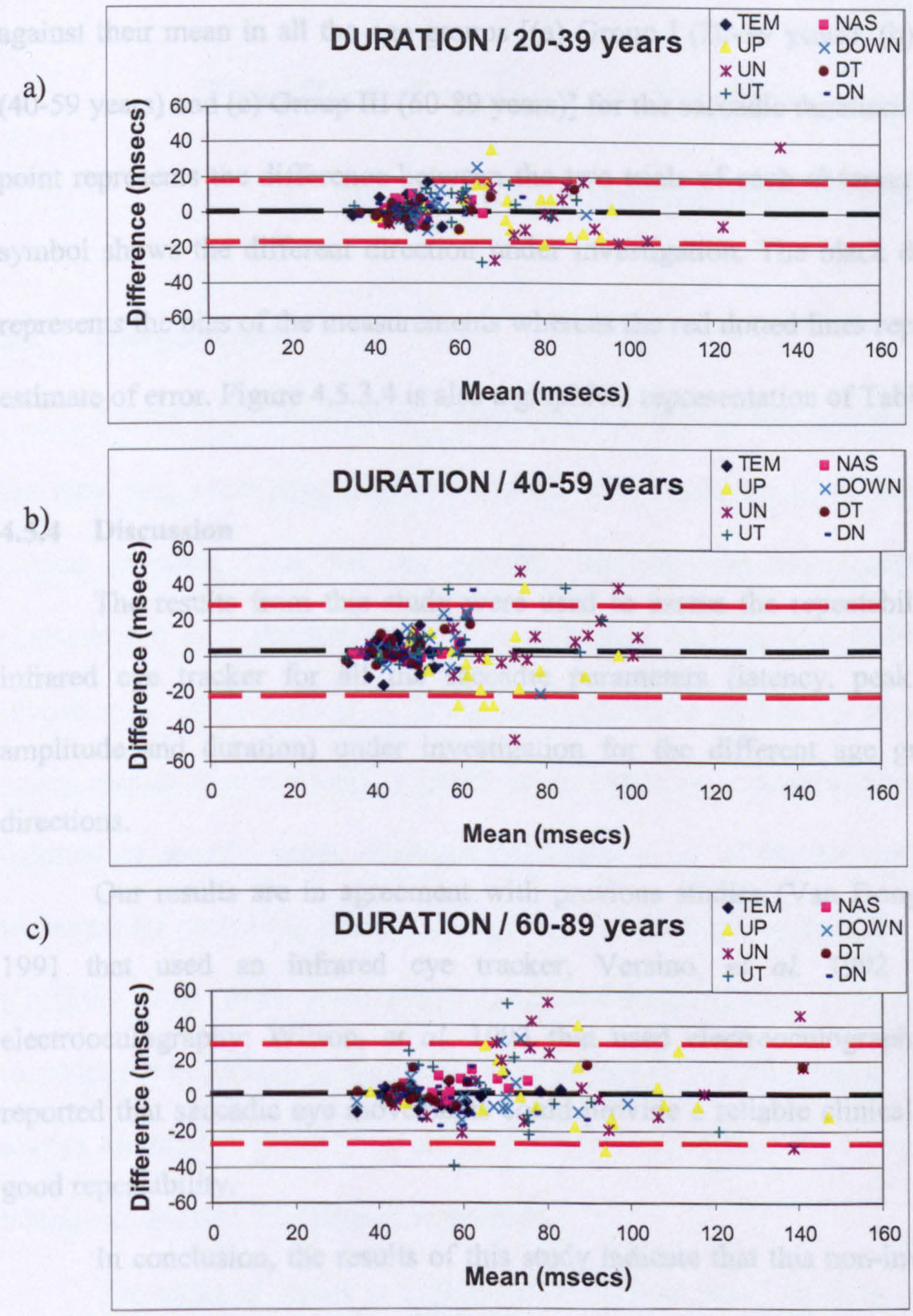


Figure 4.5.3.4: These plots correspond to (a) young group (Group I: age range 20-39 years), (b) middle aged group (Group I: age range 40-59 years) and (c) elderly group (Group III: age range 60-89 years) for saccadic duration. The x-axis represents the mean between the two trials (test/retest) whereas the y-axis represents their differences. Each symbol characterises the different directions and each point represents a single individual. The black dotted lines represent the bias of the measurements whereas the red dotted lines represent the estimate of error (±1.96*STDEV$_{DIFF}$).

Figure 4.5.3.4 represents the plot of differences between the two trials against their mean in all the age groups [(a) Group I (20-39 years), (b) Group II (40-59 years) and (c) Group III (60-89 years)] for the saccadic duration. Each data point represents the difference between the two trials of each observer and each symbol shows the different direction under investigation. The black dotted line represents the bias of the measurements whereas the red dotted lines represent the estimate of error. Figure 4.5.3.4 is also a graphical representation of Table 4.5.3.5

4.5.4 Discussion

The results from this study were used to assess the repeatability of the infrared eye tracker for all the saccadic parameters (latency, peak velocity, amplitude and duration) under investigation for the different age groups and directions.

Our results are in agreement with previous studies (Van Dongen, *et al.* 1991 that used an infrared eye tracker; Versino, *et al.* 1992 that used electrooculography; Wilson, *et al.* 1993 that used electrooculography), which reported that saccadic eye movements could provide a reliable clinical tool with good repeatability.

In conclusion, the results of this study indicate that this non-invasive eye movement recording apparatus (IRIS 6500) gives repeatable results for saccadic eye movements out to 10 degrees. The good repeatability of this non-invasive eye movement recording apparatus supports its suitability for use in a clinical environment in order to measure and use saccadic eye movements as a diagnostic and/or monitoring tool.

CHAPTER 5:

The effect of ageing and direction in saccadic eye movements: Establishing normative data.

5.1 Introduction

Ageing is a normal development in every form of life; therefore it is one of the most important physiological variables that should be taken into account in clinical research. Over the last decades, saccadic eye movements have been characterized as a sensitive test for neurological diseases like multiple sclerosis (Flipse *et al.* 1997; Serra *et al.* 2003); as a productive method for investigating the neural control of motor activity (Abel, *et al.* 1983); as a sensitive parameter of the function of specific brain structures (Tedeschi, *et al.* 1989); as well as a useful technique for evaluating effects of drugs and the index of psychomotor performance (Griffiths, *et al.* 1984; Glue, 1991). Leigh and Kennard (2004) have revealed that saccades are becoming an important research tool in clinical science. Therefore it is always essential to assess what constitutes normality in saccadic eye movements by taking into account the effect of senescence.

The effect of ageing in different saccadic parameters (latency, peak velocity, accuracy and duration) in horizontal directions is better documented than those in vertical and oblique directions. Among the studies reporting the effect of senescence there are several consistencies as well as discrepancies due to differences in the experimental design. Briefly, there is a general agreement that saccadic latencies (Spooner, *et al.* 1980; Abel, *et al.* 1983; Warabi, *et al.* 1984; Sharpe and Zackon, 1987; Hotson and Steinke, 1988; Pitt and Rawles, 1988; Tedeschi, *et al.* 1989; Versino, *et al.* 1992; Huaman and Sharpe, 1993; Wilson, *et al.* 1993; Moschner and Baloh, 1994; Baloh, *et al.*1996; Fahle and Wegner 2000) and durations (Spooner, *et al.* 1980; Warabi, *et al.* 1984; Munoz et al. 1998) increase with ageing. In contrast, the review of the literature has revealed that the effect of senescence on saccadic peak velocity and amplitude is inconsistent. Several studies have reported no consistent variation in peak velocities (Henriksson, *et al.* 1980; Abel, *et al.* 1983; Hotson and Steinke 1988; Huaman and Sharpe 1993; Munoz, *et al.* 1998; Shatig-Antonacci *et al.* 1999) and amplitudes (or accuracy) (Warabi, *et al.* 1984; Rosenhall, *et al.* 1987; Hotson and Steinke 1988; Moschner and Baloh, 1994; Scialfa, *et al.* 1994; Abrams *et al.* 1998) with ageing. However, there are studies that have reported significant decrease for saccadic peak velocity (Spooner, *et al.* 1980; Pitt and Rawles, 1988; Hotson and Steinke 1988;Tedeschi, *et al.* 1989; Bono, *et al.*1996; Fahle and Wegner 2000) and amplitude values (Chamberlain, 1971;Abel, *et al.* 1983; Sharpe and Zackon, 1987; Doig and Boylan, 1989; Tedeschi, *et al.* 1989;Huaman and Sharpe, 1993; Olincy, *et al.* 1997) in the elderly (for extensive review see Chapter 2).

Another factor that has been investigated in relation to the metrics of saccadic eye movements is the effect of direction. A review of the literature has indicated that the majority of the studies on saccadic eye movements do not report a comparison between the several directions under investigation. However, there are several studies that have reported either a direction effect (TEM vs NAS and/or UP vs DOWN and/or vertical vs. horizontal) on all the saccadic parameters or on specific ones (latency or peak velocity or amplitude and duration).

Rosenhal, *et al.* (1987) reported that the saccadic parameters obtained during binocular observations were the same in the temporal and nasal direction respectively. Therefore, they were calculated and analyzed as a single population. Similar results were also reported by a study using electroculography (Versino, *et al.* 1992) that also combined the data from the nasal and temporal direction in one set. In addition, Bono, *et al.* (1996) revealed that their monocular recording saccades using a Nystam system showed no differences in the horizontal direction between the temporal and nasal direction of gaze.

Even though there are several reports of directional comparisons (TEM vs. NAS and/or UP vs. DOWN and/or vertical vs. horizontal), they have been characterized as tentative (Becker 1991). Therefore it may be more sensible if we examined this effect with caution.

The aim of this study is to establish baseline data on saccadic parameters (latency, peak velocity, amplitude and duration) in all eight different directions of gaze [temporal (TEM), nasal (NAS), up (UP), down (DOWN), up nasal (UN), down temporal (DT) up temporal (UT) down nasal (DN)] using a non-invasive eye movement recording technique (IRIS 6500 infrared eye tracker). This will allow to investigate the clinical use of saccadic eye movements and this non-invasive recording methodology by comparing the responses of normal observers across a wide age range and those from patients.

5.2 Methods

5.2.1 Stimulus / Eye movement apparatus / Recording system

The same apparatus (infrared eye-tracker, IRIS 6500) and methodology (set up and protocols) was used in this study as those described in Chapters 3 and 4.

5.2.2 Observers

The same sixty visually normal observers recruited from the staff and student population of University of Bradford as well as the volunteers' from University Eye Clinic participated in this study as in Chapter 4.

5.2.3 Experimental procedure /Data processing

The same experimental procedure was also followed in this study as the one described in the previous Chapter. Briefly, monocular recordings of 10-degree out saccadic eye movements in eight different directions of gaze (TEM, NAS, UP, DOWN, UN, DT, UT, DN) were collected. The data processing in this study is identical to that described in Chapter 3 (section 3.4.1).

5.3 Results

For each subject individual values for all saccadic parameters (latency, peak velocity, amplitude and duration) were obtained in all directions. The average and standard deviation was calculated from four repeated measurements for each individual. Additionally, the mean value and the standard error of the mean (SEM) of each age group were also calculated for all saccadic parameters.

The statistical package that was used to analyse this set of data was SPSS 11 for Windows. A repeated mixed design ANOVA was applied in each saccadic parameter separately in order to investigate the effect of ageing on this parameters as well as the effect of direction. The within-subject factor was direction due to the fact that all our 60 observers participated in the same conditions (8 directions) of the experiment, whereas the between-subject factor was age since one observer could only participate in one age group.

5.3.1 Latency

The analysis of variance revealed a highly significant effect of ageing on saccadic latency ($F_{2,57} = 15.16$, $p < 0.001$). This result indicates that observers of each age group performed differently (Figure 5.3.1.1). A pairwise comparison revealed that the young and middle aged group performed similarly with mean latencies of 242±6 msecs and 256±6 msecs respectively. The older age group showed significantly prolonged latencies 289±6 msecs compared to the other two age groups.

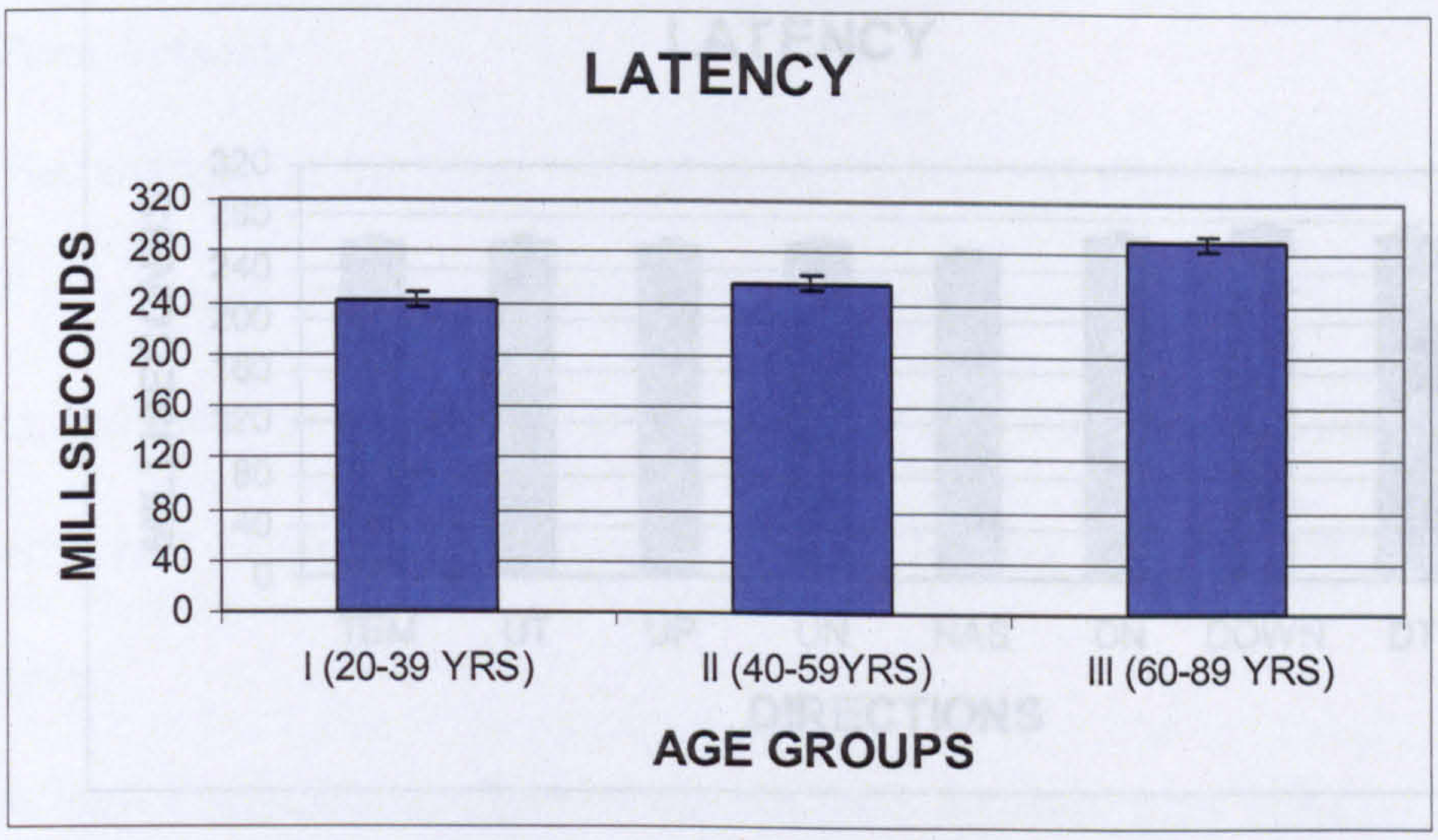


Figure 5.3.1.1: Average latency values of all directions for each age group separately. (I) corresponds to the young age group with an age range 20-39 years, (II) corresponds to the middle-aged group with an age range 40-59 years and (III) corresponds to the elderly group with an age range 60-89 years The error bars are ±1 standard error of the mean.

In addition, there was also a highly significant effect of direction on saccadic latency ($F_{7,399} = 5.63$, $p < 0.001$). This result reveals that observers performed significantly different in the several directions under investigation (Figure 5.3.1.1).

Pairwise comparisons indicated a difference between the mean latency of the nasal (NAS) direction when compared to those with a downward element (DOWN, DT, DN). Observers in these latter directions showed longer latencies by an average of 20 msecs than the nasal one. Saccades in other directions that revealed significantly different latency values were the vertical directions (UP versus DOWN). Observers in the up direction had significantly shorter latencies by approximately 16 msecs than the down direction.

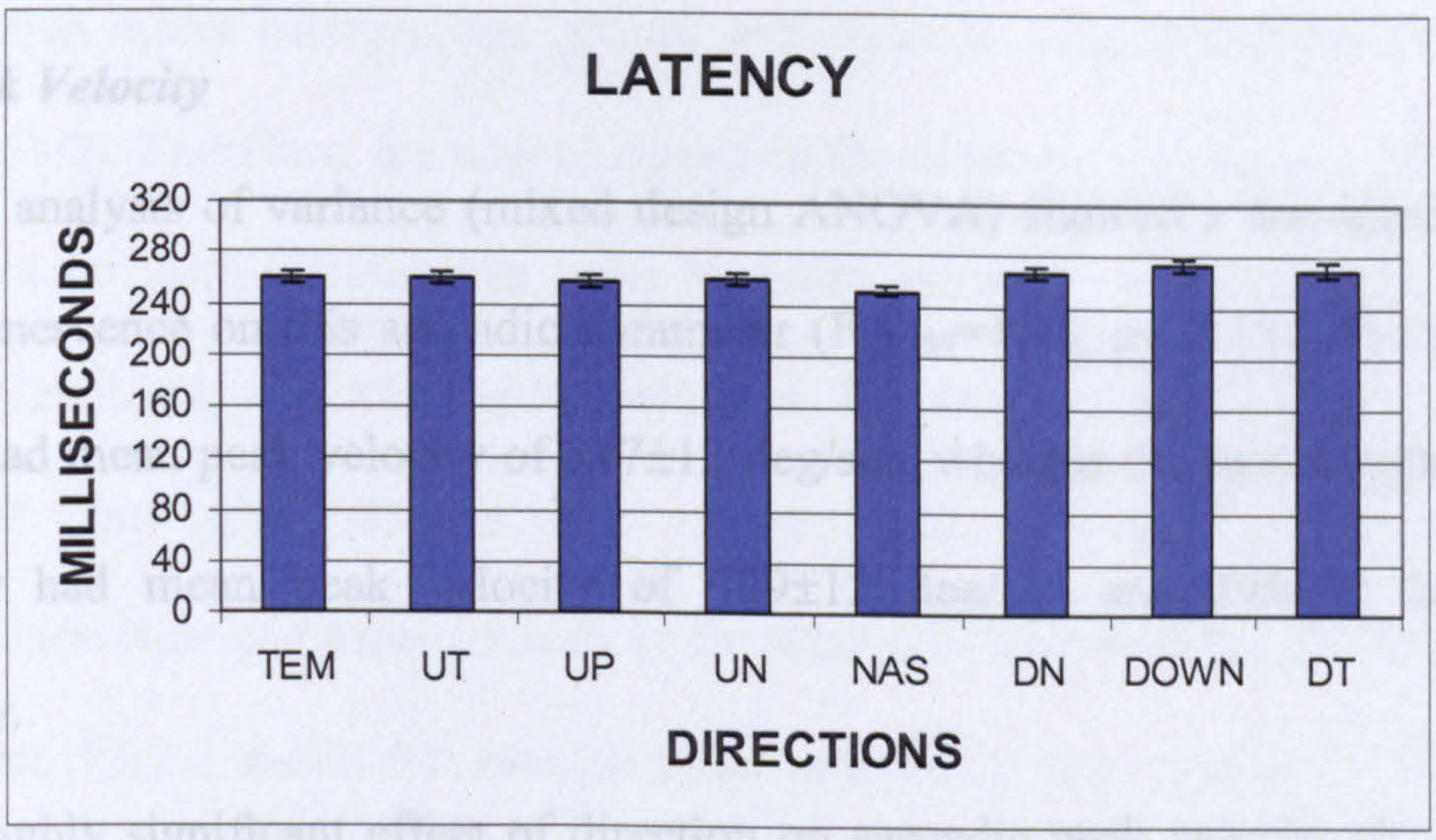


Figure 5.3.1.2: Average latency values of all observers for each direction separately. The error bars indicate ±1 standard error of the mean.

The interaction effect between age and direction was not significant ($F_{14,399}$ = 1.25, p= 0.24). This result indicates that the pattern of latency values across the directions was not significantly different between the three age groups. Figure 5.3.1.3 shows the average latency for all observers in each age group and direction.Error bars show ±1 standard error of the mean.

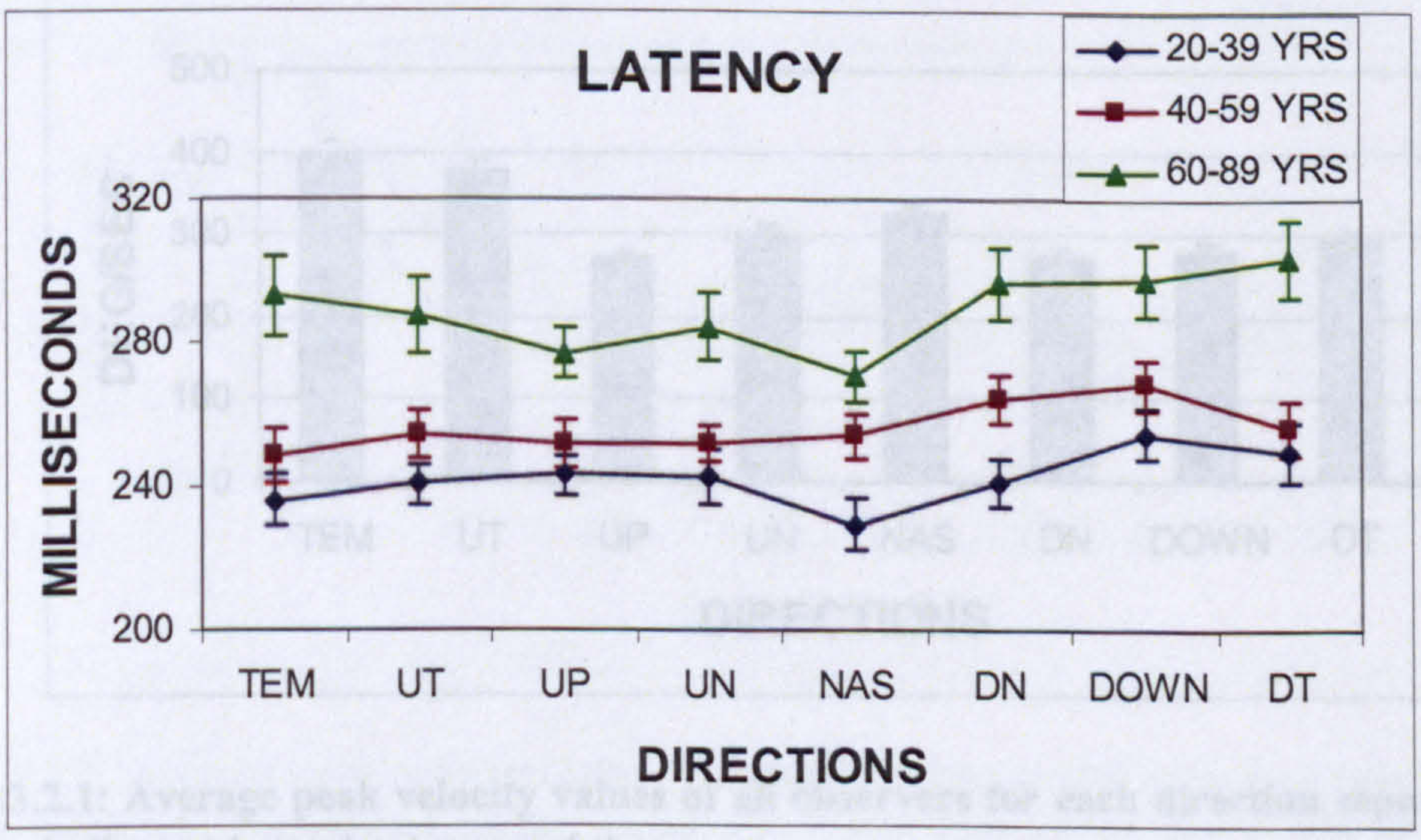


Figure 5.3.1.3: Average latency values for each age group and each direction separately. The blue diamonds correspond to the young age group (age range 20-39 yrs); the magenta square correspond to the middle age group (age range 40-59 yrs); green triangles correspond to the elderly age group (age range 60-89 yrs). The error bars are ±1SEM.

5.3.2 Peak Velocity

The analysis of variance (mixed design ANOVA) showed a non-significant effect of senescence on this saccadic parameter ($F_{2, 57}$=1.76, p= 0.18). The young observers had mean peak velocity of 317±12 deg/sec, whereas the middle aged and the elderly had mean peak velocity of 329±12 deg/sec and 298±12 deg/sec respectively.

A highly significant effect of direction on saccadic peak velocity ($F_{7, 399}$ = 20.61, p<0.001) was also found. Pairwise comparisons revealed differences among the directions in many levels. The saccadic peak velocities in the temporal (TEM) and up-temporal (UT) directions were significantly faster compared to all the other directions. In addition, observers in both vertical (UP, DOWN) and the down-nasal (DN) directions had significantly slower peak velocities than the nasal (NAS) direction (Figure 5.3.2.1).

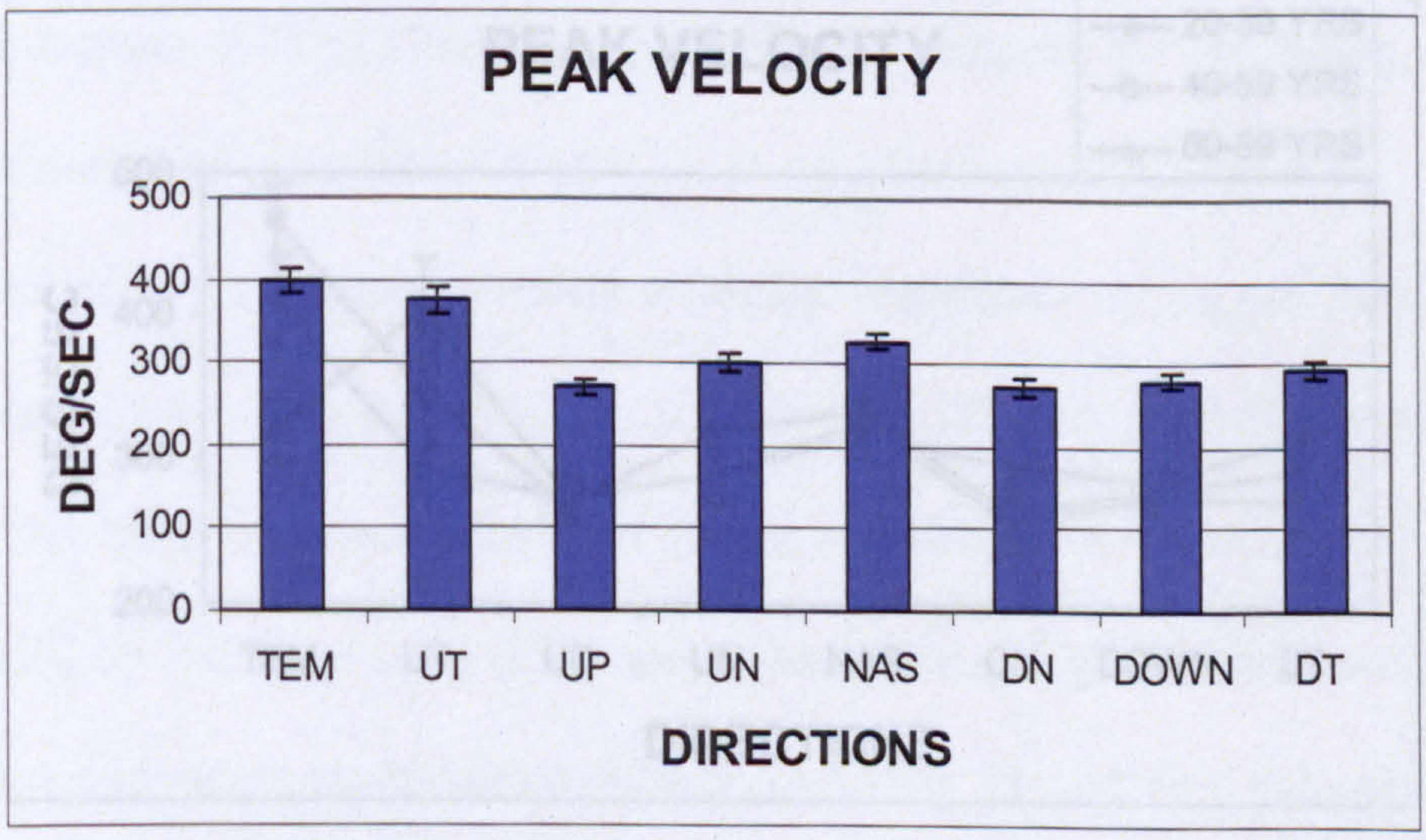


Figure 5.3.2.1: Average peak velocity values of all observers for each direction separately. The error bars indicate ±1 standard error of the mean.

Figure 5.3.2.2 shows the average peak velocity value for each age group across the different directions. The error bars indicate standard error of the mean.

The interaction effect between age groups and direction was significant ($F_{14,399} = 2.46$, $p = 0.002$). Therefore, the way observers in the different age groups performed was different for each direction. In order to verify the level where the interaction effect was significant, we looked at the contrasts. The only interaction that indicated a significant value ($p=0.003$) was when saccadic peak velocities in the temporal (TEM) direction were compared to those in the nasal (NAS) across the age groups.

Figure 5.3.2.3 shows the average peak velocity in the temporal (TEM) and nasal (NAS) directions across the three age groups. The error bars are not included in this figure for reasons of clarity. Non-parallel lines indicate a significant interaction effect (Field, 2000). Therefore, a visual inspection of Figure 5.3.2.3 shows that observers in the different age groups had different mean peak velocities in the temporal (TEM) direction but similar ones in the nasal (NAS) direction. No other interaction effect was found significant in the remaining directions.

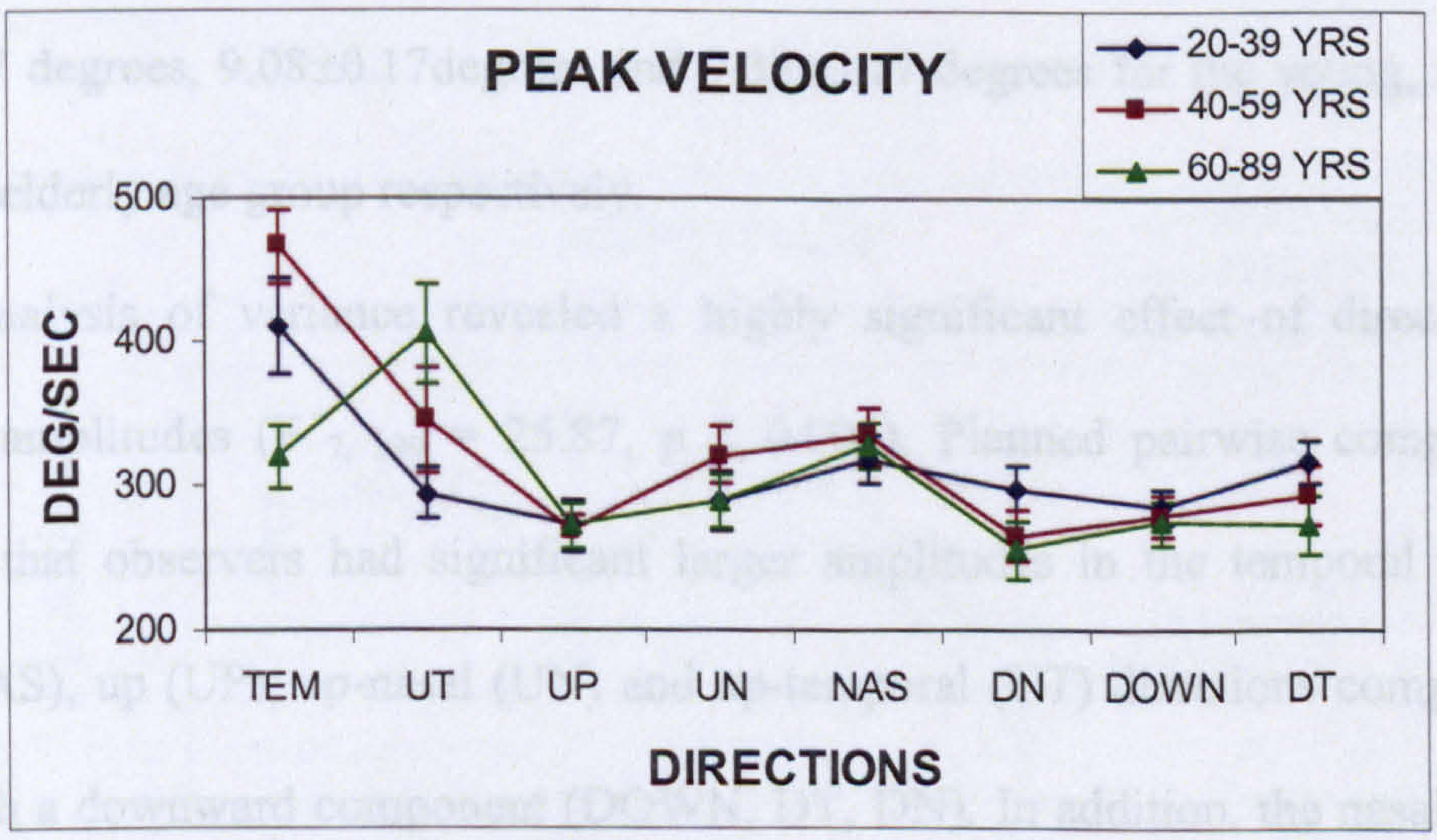


Figure 5.3.2.2: Average peak velocity values for each age group and each direction separately. The blue diamonds correspond to the young age group (age range 20-39 yrs); the magenta squares correspond to the middle age group (age range 40-59 yrs); green triangles correspond to the elderly age group (age range 60-89 yrs). The error bars are ±1SEM.

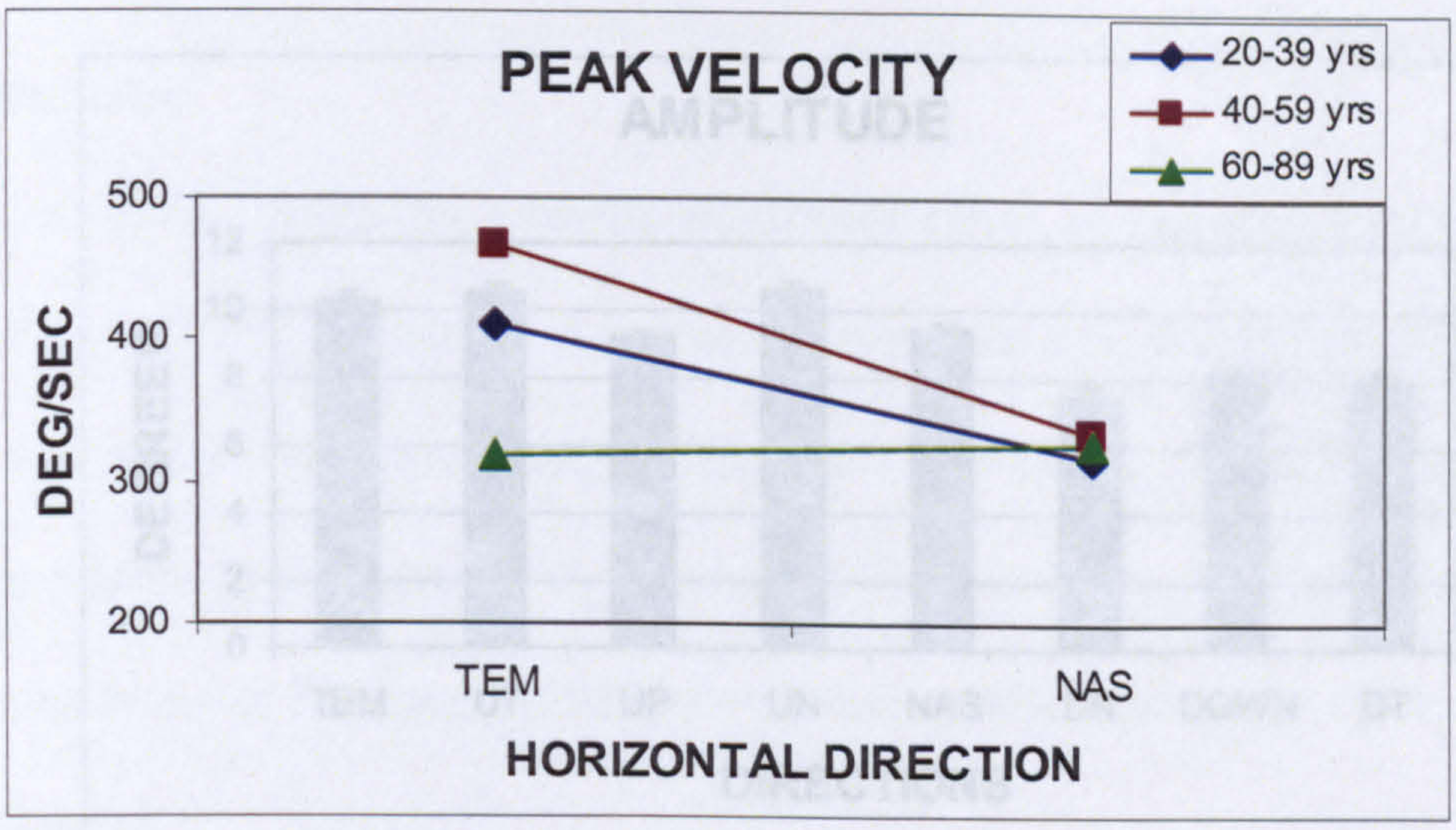


Figure 5.3.2.3: Average peak velocity values for each age group in the temporal (TEM) and nasal (NAS) directions separately. The error bars are not included for clarity reasons.

5.3.3 Amplitude

The statistical analysis showed a non-significant effect of ageing on the saccadic amplitude values ($F_{2,57}$=0.61, p=0.55). The mean amplitudes were 9.28±0.17 degrees, 9.08±0.17degrees and 9.32±0.17 degrees for the young, middle-aged and elderly age group respectively.

Analysis of variance revealed a highly significant effect of direction on saccadic amplitudes ($F_{7,399}$ = 25.87, p < 0.001). Planned pairwise comparisons revealed that observers had significant larger amplitudes in the temporal (TEM), nasal (NAS), up (UP), up-nasal (UN) and up-temporal (UT) directions compared to those with a downward component (DOWN, DT, DN). In addition, the nasal (NAS) and up (UP) directions revealed significantly lower amplitudes to the oblique directions with an upward element (UN, UT) (Figure 5.3.3.1).

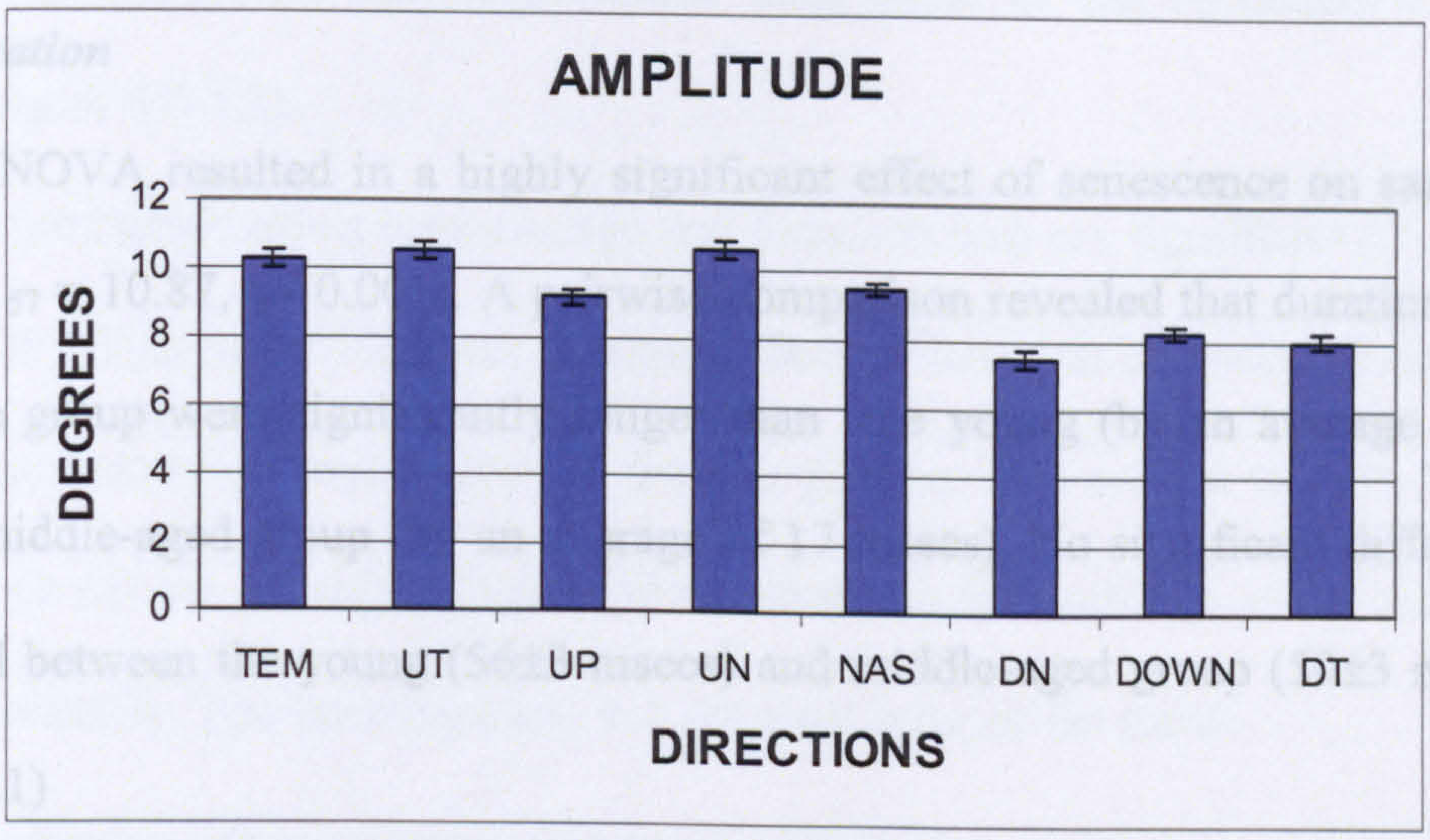


Figure 5.3.3.1: Average amplitude values for all observers in each direction separately. The error bars indicate ±1 standard error of the mean.

The interaction effect between age groups and directions was not significant ($F_{14,399} = 1.58$, $p= 0.08$). This result indicates that the variation in amplitude with direction was similar for each age group (Figure 5.3.3.2). Error bars are ±1 standard error of the mean.

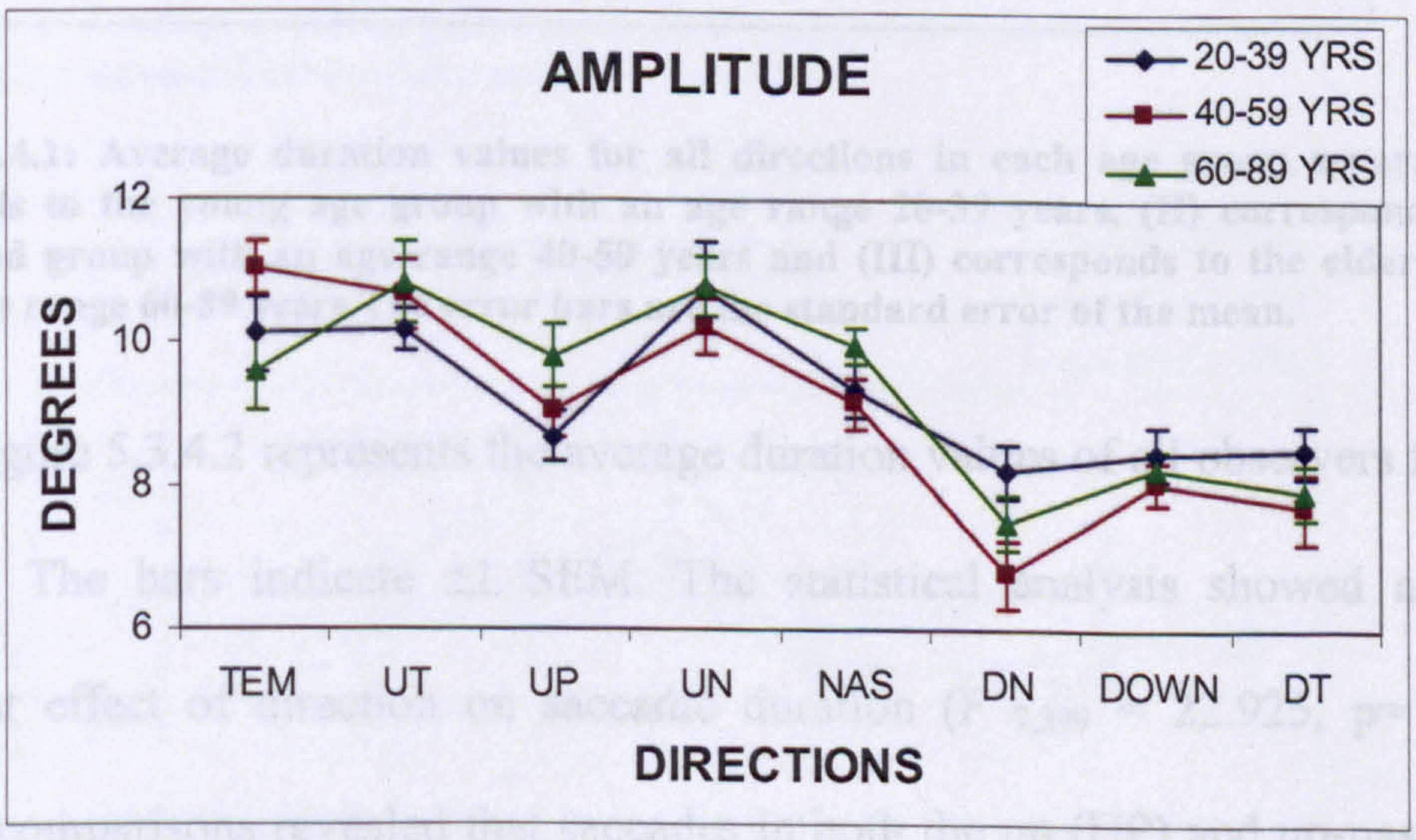


Figure 5.3.3.2: Average amplitude values for each age group and each direction separately. The blue diamonds correspond to the young age group (age range 20-39 yrs); the magenta squares correspond to the middle age group (age range 40-59 yrs); green triangles correspond to the elderly age group (age range 60-89 yrs). The error bars are ±1SEM.

5.3.4 Duration

An ANOVA resulted in a highly significant effect of senescence on saccadic duration ($F_{2, 57} = 10.87$, $p < 0.001$). A pairwise comparison revealed that durations for the older age group were significantly longer than the young (by an average of 12 msecs) and middle-aged group (by an average of 17 msecs). No significant difference was observed between the young (56±3 msecs) and middle-aged group (50±3 msecs) (Figure 5.3.4.1)

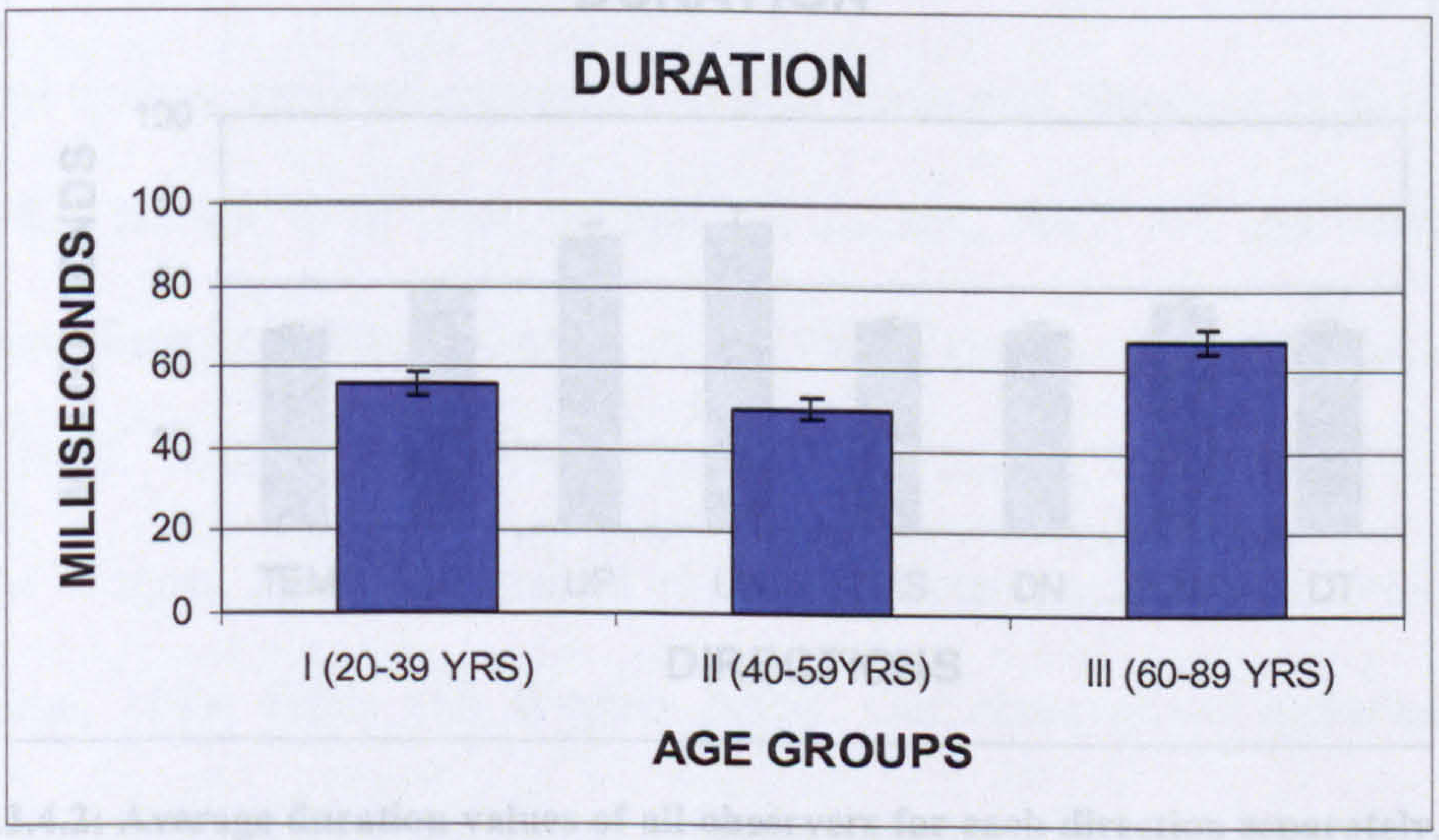


Figure 5.3.4.1: Average duration values for all directions in each age group separately. (I) corresponds to the young age group with an age range 20-39 years, (II) corresponds to the middle-aged group with an age range 40-59 years and (III) corresponds to the elderly group with an age range 60-89 years The error bars are the standard error of the mean.

Figure 5.3.4.2 represents the average duration values of all observers for each direction. The bars indicate ±1 SEM. The statistical analysis showed a highly significant effect of direction on saccadic duration ($F_{7,399} = 22.925$, $p = 0.001$). Pairwise comparisons revealed that saccades in both the up (UP) and up-nasal (UN) directions were significantly longer in durations compared to all the other directions. In addition, saccades in the temporal (TEM), nasal (NAS) and down temporal (DT) directions had significant shorter durations than those in the up-temporal (UT) direction (Figure 5.3.4.2).

The interaction effect between age and direction was not significant ($F_{14,399}$ = 1.22, p= 0.26). This result indicates that the effect of direction on saccadic duration was not significantly different between the age groups. This can be seen in Figure 5.3.4.3 that shows the average duration of all observers for each age group and each direction separately. The error bars are ± 1 standard error of the mean.

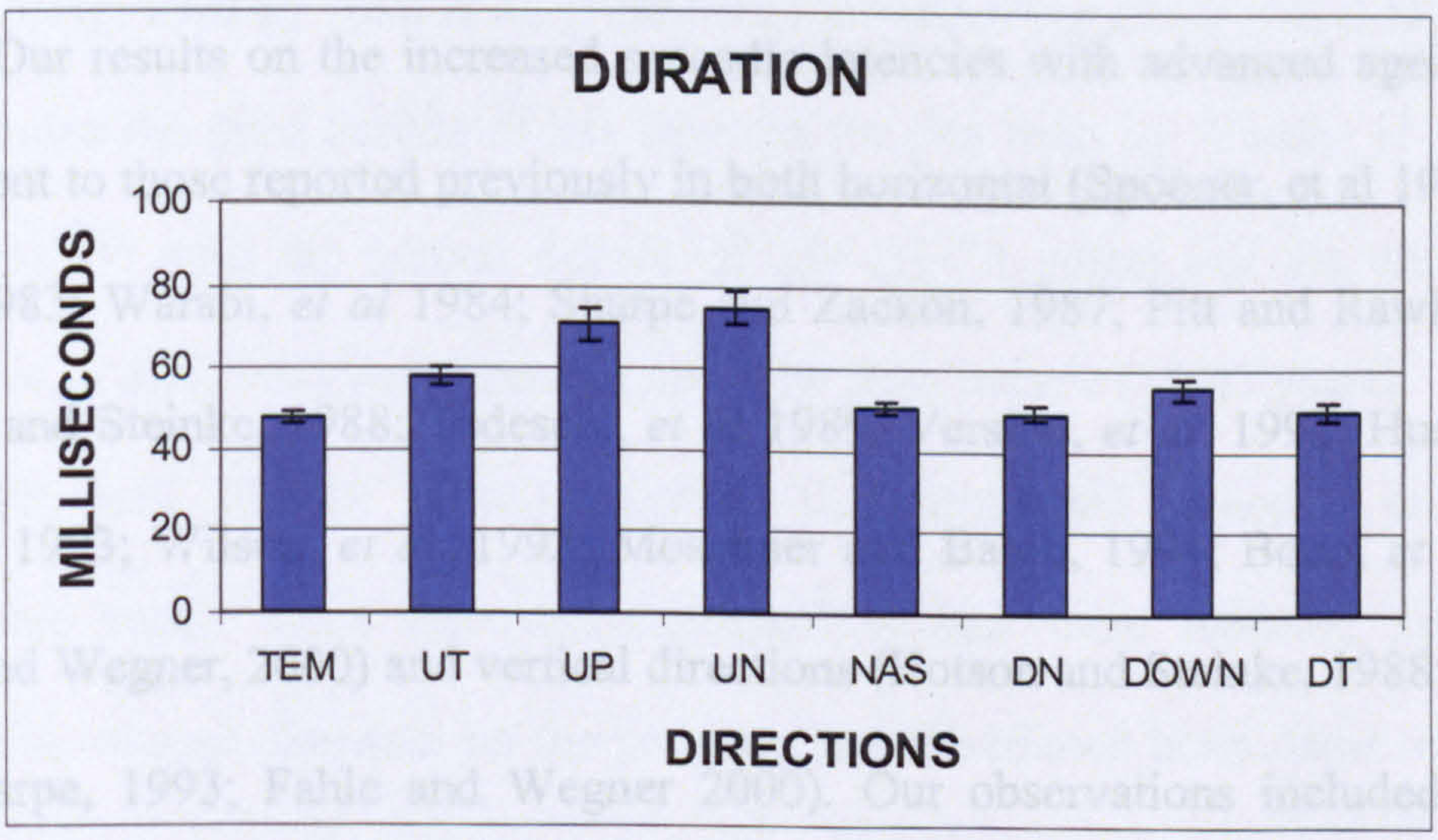


Figure 5.3.4.2: Average duration values of all observers for each direction separately. The error bars indicate ± standard error of the mean.

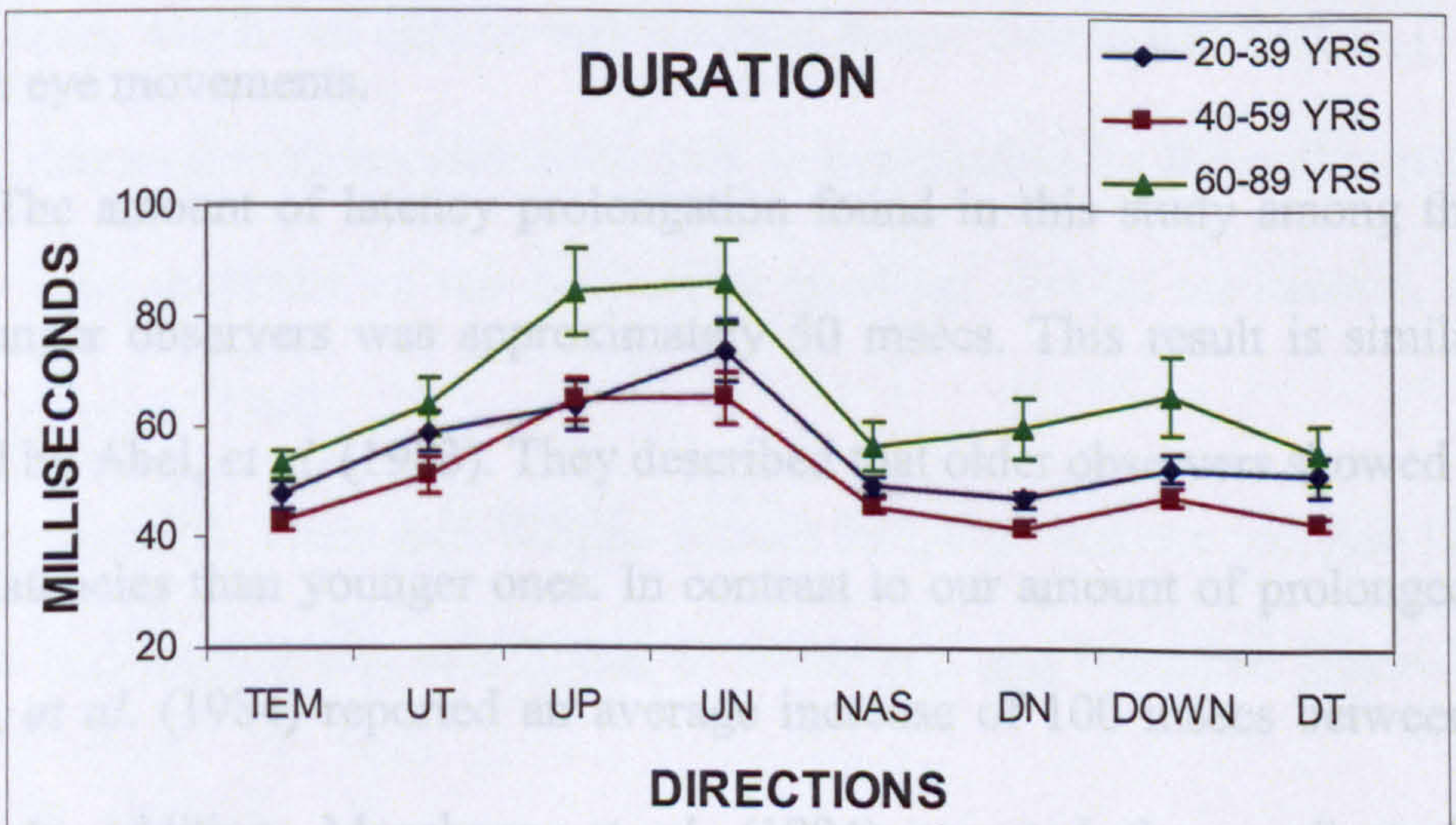


Figure 5.3.4.3: Average duration values of all observers for each age group and each direction separately. The error bars are ±1SEM.

5.4 Discussion

5.4.1 Effect of ageing

The results from this study show that saccadic latency and duration are dependent on senescence with the elderly group having increased values compared to the young and middle-aged groups. No such effect was observed between the two latter groups. Our statistical analysis also revealed no significant effect of ageing on saccadic amplitudes and peak velocities.

5.4.1.1 Latency

Our results on the increased saccadic latencies with advanced ageing are in agreement to those reported previously in both horizontal (Spooner, et al 1980; Abel, *et al.* 1983; Warabi, *et al* 1984; Sharpe and Zackon, 1987; Pitt and Rawles, 1988; Hotson and Steinke, 1988; Tedeschi, *et al* 1989; Versino, *et al.* 1992; Huaman and Sharpe, 1993; Wilson, *et al.* 1993; Moschner and Baloh, 1994; Bono, *et al.* 1996; Fahle and Wegner, 2000) and vertical directions (Hotson and Steinke, 1988; Huaman and Sharpe, 1993; Fahle and Wegner 2000). Our observations included also the oblique directions of gaze and found a similar increase. To our knowledge there are no previous studies reporting the effect of senescence on directly recorded oblique saccadic eye movements.

The amount of latency prolongation found in this study among the elderly and younger observers was approximately 50 msecs. This result is similar to that reported by Abel, *et al.* (1983). They described that older observers showed 45 msecs longer latencies than younger ones. In contrast to our amount of prolonged latency, Warabi, *et al.* (1984) reported an average increase of 100 msecs between the two groups. In addition, Moschner, *et al.* (1994) reported the smallest difference, approximately 20 msecs between the age groups. There are potential reasons this occurs. Firstly, a number of methodological issues may be responsible. Warabi *et al.* (1984) and Moschner *et al.* (1994) used an electroculography technique in contrast to Abel *et al.* (1983) and our study where an infrared reflectance recording methodology was used. Another explanation may be given by the different number of observers used as well as the age distribution among the age groups. Warabi, *et al.* (1984) recorded saccadic eye movements in 34 individuals, whereas Abel, *et al.* (1983) used 44 observers and Moschner, *et al.* (1994) used 84 observers respectively. The age range used by Abel *et al.* (1983) for the young age group was similar to ours and included the third decade of life whereas the one used by Warabi, *et al.* (1984) was "limited" until the second decade of life (16-26 years) and the one used by Moschner, *et al.* (1994) was extended up to the forth decade (18-43 years).

Pitt and Rawles (1988) reported that prolonged latencies are not an unexpected result since electrophysiological studies have reported age related changes on several elements on the pathway and the related brain areas involved in the generation and triggering of saccadic eye movements. Creasy and Rapoport (1985) revealed that during normal ageing there is a selective cerebral neural degeneration, which can explain this saccadic delay. Sharpe and Zackon (1987) also revealed that a cerebral atrophy could give an explanation for the prolonged latencies but they were uncertain on the mechanism involved. Similar explanation was given by Munoz, *et al.* (1998).

In addition, Fahle and Wegner (2000) indicated that the increase in saccadic latencies with ageing was mostly due to attentional and cognitive factors and not a motor problem. They based their interpretations on the fact that the reaction times improved in the elderly in the gap condition[14].

In summary, the most consistent finding in the eye movement field is the increased saccadic latency, which can be explain by the increased central processing or the reduction in the transmissibility among the neurons in the several cortical areas involved in the saccadic eye movements identified in the ageing brain (Sharpe and Zackon 1987; Pitt and Rawles 1988; Ciuffreda and Tannen 1995).

5.4.1.2 Peak Velocity

The effect of ageing on saccadic peak velocities has shown contradictory results among the numerous studies. In accord to previous studies (Abel, *et al.* 1983; Huaman and Sharpe, 1993; Shafiq-Antonacci, *et al.* 1999), our study demonstrates no significant effect of senescence on saccadic peak velocity in all the directions of gaze under investigation for a 10-degree saccadic amplitude. There are several other studies that our results are in agreement with only for small saccadic amplitudes (Henriksson, *et al.* 1980;Warabi, *et al.* 1984; Sharpe and Zackon, 1987; Hotson and Steinke, 1988; Wilson, *et al.* 1993; Moschner and Baloh, 1994; Munoz, *et al.* 1998). However, they found a decrease of peak velocity with increased stimulus magnitude

Shafiq-Antonacci, *et al.* (1999) reported that their finding of unchanged peak velocities as a function of age was supported by histological observations (Brody and Vijayashankar, 1977) and attributed on the lack of neuronal degeneration in the brainstem reticular formations of the elderly. Similar results were also reported by Huaman and Sharpe (1993) in the vertical directions. They reported that normal peak velocities signify that burst neurons in the rostral interstitial nucleus of the medial

[14] Gap condition is the one where the old fixation point disappears for a certain time before the new one appears.

longitudinal fasciculus and paramedian pontine reticular formation are unaffected by age. Their results were also confirmed by other histological examination, which identified that the neurons in the midbrain or the pontine reticular formation were preserved of senescence (Brody and Vijayashankar 1977). The results from these studies and ours may denote that even though different pathways are involved in the generation of horizontal and vertical eye movements, senescence seems to have no effect on them.

In contrast, some others have reported significant ($p < 0.01$) decrease of peak velocity in the elderly in horizontal (Spooner, *et al.* 1980; Pitt and Rawles, 1980; Tedeschi, *et al.* 1988; Bono, *et al.* 1996; Fahle, *et al.* 2000) and in vertical directions (Steinke and Hotson, 1988; Fahle, *et al.* 2000).

These contradictory results can be attributed mostly on methodological reasons. This may include different recording apparatus, different tasks and saccadic angles as well as differences in the mean age range, different ways of analysis or even differences on the selection criteria of the observers without considering certain parameters (medication, general health) that may have an effect on the saccadic function.

Each study explained this decrease in peak velocity values with ageing to several factors. Tedeschi, *et al.* (1989) suggested that the decrease in the peak velocity in their results could be explained by the effect of ageing on the brainstem saccadic generator that controls saccadic peak velocities. They have also reported that this effect is relatively smaller to the one observed in the higher levels involved in the programming of the correct execution of saccadic eye movements. Pitt and Rawles (1988) also revealed that peak velocity changes are dependent on the activity on the oculomotor neurons but they were not certain at which level of this complex system ageing has an effect. Moschner and Baloh (1994) reported that age dependent changes on neural elements within the frontal eye fields, parietal cortex and basal ganglia may lead to decreased saccadic peak velocities.

These differences across the several studies on the effect of ageing on saccadic eye movements may help to conclude in agreement to the observation by Tedeschi *et al* (1989), that the effect of ageing on this saccadic parameter is very scattered or that the areas of the brain, which are involved in the control of saccadic peak velocity show a selective vulnerability to senescence.

5.4.1.3 Amplitude

Saccadic amplitude has been reported also as gain and accuracy among the several studies. Our results agree to those reported previously that there is no effect of ageing on this parameter for both horizontal (Warabi, *et al* 1984; Rosenhall, *et al.* 1987; Moschner and Baloh, 1994; Scialfa, *et al.* 1994; Abrams, *et al* 1998) and vertical directions (Hotson and Steinke, 1988). This result suggests that the functions for programming the appropriate size of saccade may be relatively preserved by ageing.

Additionally, they are several studies that contradict the previous notion and have reported that accuracy or amplitude decreases with senescence in both horizontal (Abel, *et al.* 1983; Sharpe and Zackon, 1987; Doig and Boylan, 1989; Tedeschi, *et al* 1989; Olincy, *et al.* 1997) and vertical directions (Chamberlain, 1971; Huaman and Sharpe, 1993).

Sharpe and Zackon (1987) found hypometric saccades and reported that this might be due to a deficient motor error signal. Huaman and Sharpe (1993), who also reported decreased accuracy in the vertical directions, explained this observation due to the loss of cerebral cortical neurons or cerebellar Purkinje cells in the ageing brain. It is also mentioned that the motor command that generates saccades, is transmitted from the cerebral cortex to the burst neurons in the paramedian pontine reticular formation. Olincy *et al* (1997) also reported that the increased hypometric saccadic eye movements observed in the elderly could be due to a poor ability of the oculomotor system to generate the desired eye position. Age dependent changes upon these areas have been reported previously (Creasey and Rapoport, 1985).

5.4.1.4 Duration

Our results demonstrate that saccadic durations are increased with ageing. Similar results have also been reported by other studies (Spooner, *et al.* 1980; Warabi, *et al.* 1984; Munoz, *et al.* 1998).

Warabi, *et al.* (1984) attributed this duration increment to the internal feedback mechanism used by the central nervous system in order to accomplish an accurate saccadic eye movement. In addition, Munoz, *et al.* (1998) revealed that saccadic peak velocity and duration are functions attributed to the properties of the burst generation but not to voluntary control. Therefore when these elements are relatively constant by senescence, this suggests that the saccadic burst generator and the nuclei of the extraocular muscles remain relatively unchanged by ageing. The results of this study, which demonstrates that ageing increases saccadic duration but does not alter peak velocity, imply a selective vulnerability of the burst generators and/or the nuclei of the extraocular muscles.

5.4.2 Effect of direction

The results of this study demonstrate a significant main effect of direction on all the saccadic parameters (latency, peak velocity, amplitude and duration). Previous studies have reported comparisons between the on-off directions (i.e. TEM vs. NAS, UP vs. DOWN), therefore we decided to follow the same pattern. Our recordings included also the oblique directions of gaze.

5.4.2.1 Latency

Our results show no nasal versus temporal saccadic latency asymmetries. This result is similar to the one reported by Constantinidis, *et al.* (2003) and Honda (2002). Constantinidis, *et al.* (2003) suggested that the absence of a latency asymmetry between the horizontal directions might show that the oculomotor system might be spared from cerebral dominance or this effect is reflected in other measures. No latency asymmetry was also identified within the oblique direction (UN vs. DT and UT vs. DN).

In contrast, Munoz *et al* (1998) reported that saccadic reaction times were smaller in the temporal hemifield than the nasal one. They suggested that this result might have a basis in the development of the cortex. Similar controversial to ours results were also reported from other studies (Pizollo and Rayner, 1980; Huton and Palet, 1986; Pitt and Rawles, 1988; Munoz, *et al.* 1998).

Additionally, our normative data indicated a vertical asymmetry on saccadic latencies, with the upward saccadic latencies being less delayed than the downward direction. The same results have also been reported previously (Bono, *et al.* 1996) but no explanation has been given on this observation. Bono, *et al.* (1996) suggested to look and interpret this result carefully because a significant interaction of eyelid artifacts may have occurred. In our study, the recording system used, has taken into consideration these artifacts therefore this explanation seems unlikely.

5.4.2.2 Peak Velocity

Our results are in agreement with several studies that have reported that saccades in the temporal direction are faster compared to the nasal (Robinson, 1964; Fricker and Sanders, 1975; Hallet and Adam, 1980; Collewjin, *et al.* 1988a; Becker, 1991; Fahle and Wegner, 2000). In our study, observers had faster peak velocities by an average of 71 deg/sec in the temporal direction compared to the nasal direction. In addition, a peak velocity asymmetry was found in one pair of oblique directions (UT vs. DN). This comparison indicated that observers in the DN direction had slower peak velocities than the UT direction. A potential reason why these asymmetries occur was not given by any of the studies mentioned above. Porter, *et al.* (1995) in a review on the basic and clinical aspects of the extraocular muscles, reported that motorneurons innervate the agonist and antagonist muscles in such a way that act in a push-pull fashion. A possible explanation of the asymmetry observed in our study can be endorsed in a possible mismatch in the corresponding discharge rates between the muscles that are involved.

A reverse peak velocity asymmetry (faster nasal peak velocities) between the horizontal planes has been reported in other studies (Boghen, *et al.* 1974; Bird, *et al* 1976; Miyoshi, *et al* 1981; Pitt and Rawles, 1988; Becker 1991). In addition, there are several other studies that have reported no horizontal asymmetry in the saccadic metrics (Rosenhal, *et al.* 1987; Versino, *et al.* 1992; Bono, *et al.* 1996) therefore they combined the data from the nasal and temporal direction in a single population. One might expect that the discrepancy between our results and those of Rosenhal, *et al.* (1987) and Versino, *et al.* (1992) was due to the fact that our observations were made monocularly while theirs were made binocularly. Collewijn, *et al.* (1988a) using a magnetic search coil investigated the binocular coordination of human horizontal saccadic eye movements. They reported that the viewing conditions (binocular versus monocular observation) had a non-significant effect on the saccadic parameters under investigation (peak velocity, duration, skewness of saccades in relation to their amplitude). They also reported that eye movements during monocular viewing were less well yoked than during binocular conditions. This report as well as the results reported from Bono, *et al.* (1996) (whose measurements made monocularly) indicate that this disagreement amongst these studies is not due to the viewing conditions (binocular versus monocular observations) but probably due to other methodological differences. Moreover a further investigation on possible differences (if any) between binocular and monocular recordings might be considered necessary and could give more information with respect to several diseases that affect the oculomotor system.

Hotson and Steinke (1988) revealed no significantly different peak velocity values between the upward and downward directions within. Similar results were also found by Huaman and Sharpe (1993). Our results are in agreement to the ones mentioned above but in contrast to three studies using a magnetic search coil technique. They reported that observers have faster peak velocities in the upward directions compared to the downward ones (Yee, *et al.* 1985; Collewijn, *et al.* 1988b; Becker and Jurgens, 1990). The differences between the studies can be attributed to the different recording apparatus used and the small sample of observers used by the magnetic search coil studies. No such asymmetry was identified between the peak velocity values in the UN and DT directions.

5.4.2.3 Amplitude

Our results show no horizontal and/or vertical saccadic amplitude asymmetry. These findings disagree to those reported by Fahle and Wegner (2000) in the horizontal direction and Huaman and Sharpe (1993) in the vertical directions.

Our statistical analysis showed a saccadic amplitude asymmetry in all oblique (UN vs. DT and UT vs DN) directions. Furthermore, it was observed that subjects undershoot in all directions with a downward component. These directional asymmetries may possibly be due to fact that people are more used to move their heads to look at those directions rather than their eyes. To our knowledge there are no established information on directly recorded saccadic oblique amplitudes.

5.4.2.4 Duration

As mentioned previously, there is no established information on how direction has an effect (if any) on saccadic duration. Our results show that there is a vertical and an oblique asymmetry on saccadic durations. Our findings indicate that observers needed longer durations to accomplish saccadic eye movements in the directions of gaze with an upward component (UP, UN) than with a downward component (DOWN, DT). A possible explanation to this asymmetry may be that the population of neurons responsible for the saccadic generation in these directions may have a directional prevalence.

5.5 Conclusions

In summary, this study has shown that saccadic latency and duration are affected by senescence whereas saccadic peak velocity and amplitude are independent of the ageing process. A significant effect of direction in all saccadic parameters was also found. This data set revealed that observers had smaller saccadic amplitudes in all the directions with a downward element (DOWN, DT and DN) when compared to the remaining directions of gaze.

Since our results on the effect of ageing and direction are in agreement with previous studies, we suggest that this infrared eye tracker (IRIS 6500) provides a reliable method of obtaining saccadic eye movements in humans in all directions of gaze.

CHAPTER 6:

The effect of viewing distance (far versus near) on saccadic eye movements.

6.1 Introduction

Saccadic eye movements are the rapid eye movements used to bring the line of sight onto the fovea (Wouters, *et al.* 1998; Leigh and Zee 1999). They are the most natural occurring eye movements since they are used in everyday tasks and at all viewing distances.

A review of the literature has shown that although studies on eye movements have used a variety of viewing distances, the effect of different viewing distance (far versus near) on the dynamics of saccades is not well documented. However, there is one study (Yang, *et al.* 2002) that examined the effect of viewing distance on the saccadic latencies in the horizontal direction. Yang, *et al.* (2002) reported that latencies of binocular horizontal saccades at close distance (20 cm) were shorter compared to the far ones (150 cm) in both adults and children. They also reported that to their knowledge the effect of viewing distance (far versus near) on the saccadic latency is unknown in different age groups.

In addition, there are several studies that have reported the effect of viewing distance on saccadic disconjugacy[15] (Van der Steen and Bruno, 1995; Yang, *et al.* 2002; Yang and Kapoula 2003). There is also another study that has

[15] Disconjugacy is the different signal obtained from each eye during saccadic eye movements. That signal is obtained from LE-RE. The binocular coordination is called conjugacy. This latter signal is usually obtained from (RE+LE)/2.

reported the effect of viewing distance on the generation of vertical saccades during locomotion (Moore, *et al.* 1999).

Van der Steen and Bruno (1995) recorded binocular horizontal and vertical saccadic eye movements with a magnetic search coil. They reported that viewing distance (144 cm versus 37 cm) increases the metrics and time-course of disconjugate saccades, in horizontal and vertical directions.

In another study, Yang and Kapoula (2003), using a photoelectric device, reported that the viewing distance does not have an effect on the accuracy of the saccades in adults and children but it has an effect on the saccadic disconjugacy, this being larger at close distances.

One of the general aims of this study is to determine the clinical use of a non-invasive eye movement technique. In a clinical environment, the compact nature of any clinical tool is an advantage. A reduction of working distance would help to increase the clinical convenience of the technique. Thus it is essential to know if changes in viewing distance have an effect on the metrics of saccadic eye movements obtained.

From the reviewed literature it appears that different viewing distances may produce changes in the measured values of the saccadic dynamics. Therefore, an investigation on the change (if any) on saccadic parameters when recorded at 300 cm and 49 cm will be carried out. The decision to proceed with recordings at 300 cm was based on the fact that this distance is commonly used in everyday tasks (e.g. watching television). In addition, the near distance was chosen to 49 cm due to a compromise between the habitual reading distance (30-40 cm) and establishing the same experimental condition regarding the visual angle of our stimulus as the far distance.

6.2 Methods

6.2.1 Stimulus

6.2.1.1 Far (300 cm)

The stimulus used in this distance condition is the same as the one described in Chapter 4.

6.2.1.2 Near (49 cm)

The stimulus was a white square point (4×4 pixels) moving in different directions, horizontal (180°), vertical (90°) and oblique (45°-135°). The stimulus was generated as above by computer software (PRESENTATION) and presented to the observer on a computer monitor. The resolution of the monitor was 1600×1200 pixels. The stimulus image was contained within a black rectangular screen with a horizontal extent of 34.2 cm and vertical one of 27 cm (Figure 6.2.1.1b).

The distance between the observer and the monitor (49 cm) was selected (Figure 6.2.1.1a) in order to establish an angular displacement of 15° for horizontal measurements, 10° for vertical and 15° for the oblique measurements from the primary position. At this distance, the set up produced a size of 5.6 minarc visual angle for our stimulus, similar to the one obtained in the far set up.

The contrast of the stimulus was 100%. This value was calculated by using the same formula as in Chapter 3. Our measured luminance values were $L_{stimulus}$ = 30.41 cd/m^2 for the stimulus and $L_{background}$ = 0.00 cd/m^2 for the background. In order to achieve this contrast the monitor was switched on for 40 minutes prior to any recordings.

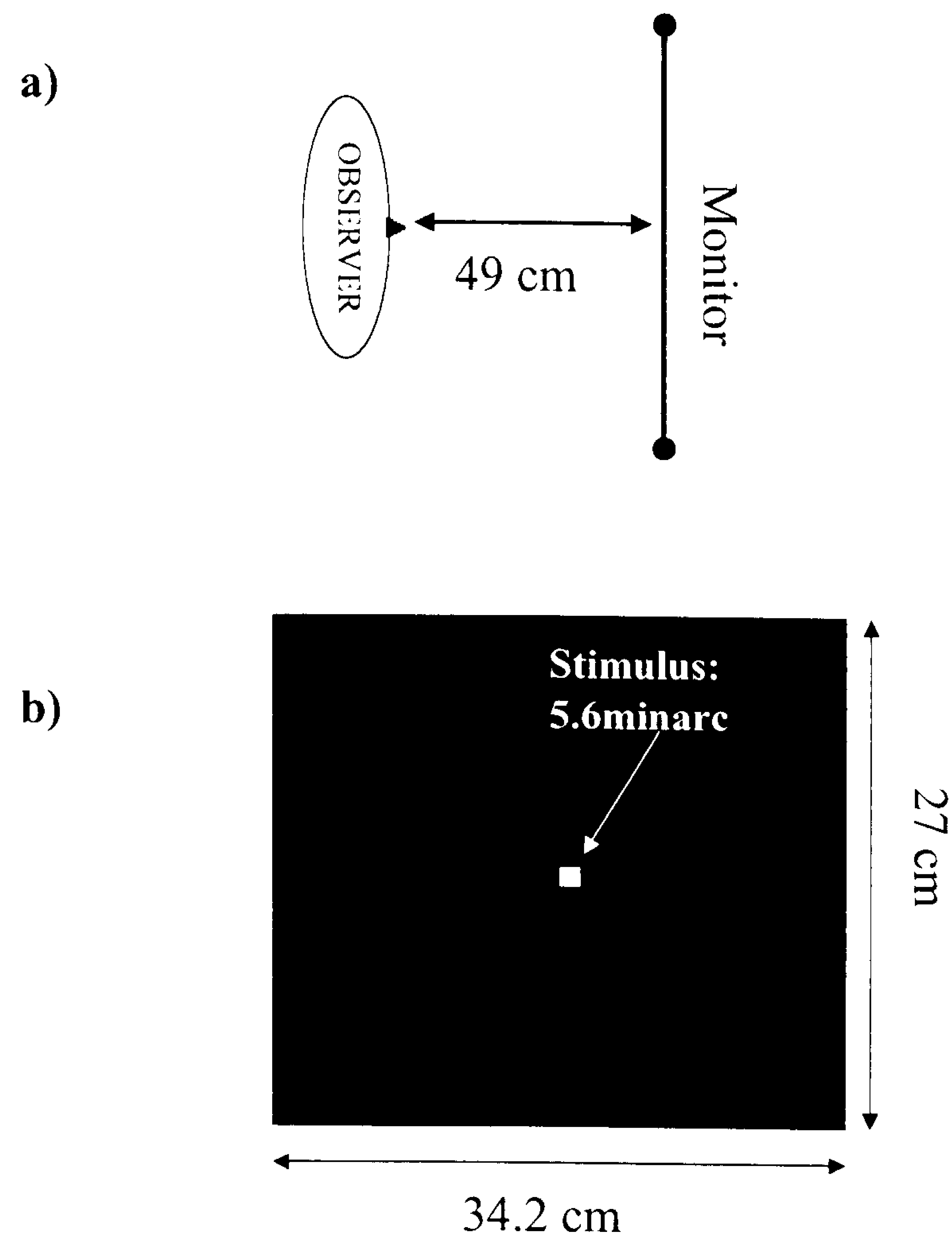


Figure 6.2.1.1: Schematic diagram of the set up system showing the distances between the observer and the monitor (49cm). The projected image was contained within a black rectangular screen with a horizontal extent of 34.2 cm and vertical one of 27 cm.

6.2.2 Eye movements apparatus / Recording system

The monitoring apparatus used in this experiment was an infrared light eye tracker (IRIS 6500) and the recording system consisted of a laptop running LABVIEW 6.1 as described previously (Chapter 3).

6.2.3 Observers

Twenty visually normal observers were recruited from the staff and student population of University of Bradford in order to participate in this study. Their ages ranged from 20 to 39 years (median 25.5 years). Thirteen of the subjects were female. Subjects participating in the study had no systemic disease and were not under medication that had any known effect on saccadic eye movements.

Prior to the collection of eye movements' data, all subjects underwent a series of preliminary optometric tests (LogMAR visual acuity, cover test, motility and stereopsis) to establish that their binocular vision was normal. All subjects demonstrated a TNO stereoscopic acuity better than 60 seconds of arc. Visual acuity in all observers was at least 0.0 LogMAR. An optical correction was used if necessary in the form of the subjects' own contact lenses or full aperture trial case lenses.

6.2.4 Experimental procedure / Data processing

The same experimental procedure was also followed in this study as the one described in Chapter 4. Briefly, monocular recordings of 10-degree saccadic eye movements in eight different directions of gaze (TEM, NAS, UP, DOWN, UN, DT, UT, DN) were collected. All measurements were repeated at both viewing distances. The data processing in this study is also identical to the one described previously.

6.3 Results

Individual values for each saccadic parameter (latency, duration, peak velocity and amplitude) were obtained in all the eight directions under investigation for all the observers at both viewing distances [far (300cm) and near (49cm)]. The average and standard deviation (STDEV) obtained from four repeated measurements for each individual were also calculated.

After verifying that the application of parametric statistics is appropriate, a repeated measures ANOVA with several independent variables was applied for each saccadic parameter (latency, peak velocity, amplitude and duration) separately. The within-subject factors were directions (eight) and viewing distances [far (300 cm) and near (49 cm)].

6.3.1 Latency

The analysis of variance revealed a non-significant effect of viewing distance on saccadic latency ($F_{1,19}$= 0.90, p= 0.35). The mean latency at 300 cm was 242±5 msecs and at 49 cm was 239±5 msecs, respectively.

However, there was a significant effect of direction on saccadic latency ($F_{7, 133}$= 4.61, p< 0.001). Pairwise comparisons showed a significant difference between the mean latency of the down (DOWN) direction compared to the nasal (NAS) direction (p=0.003) and the oblique up-nasal (UN) (p=0.002) (Figure 6.3.1.1). Observers needed longer latencies in the down direction by an average of 27 msecs to the nasal and by an average of 22 msecs when compared to the up nasal. A similar result between the nasal and down direction has been previously reported (Chapter 5 where the effect of aging and direction was investigated). This finding indicates a consistent effect of direction on saccadic latency despite the different observers, conditions and recording sessions.

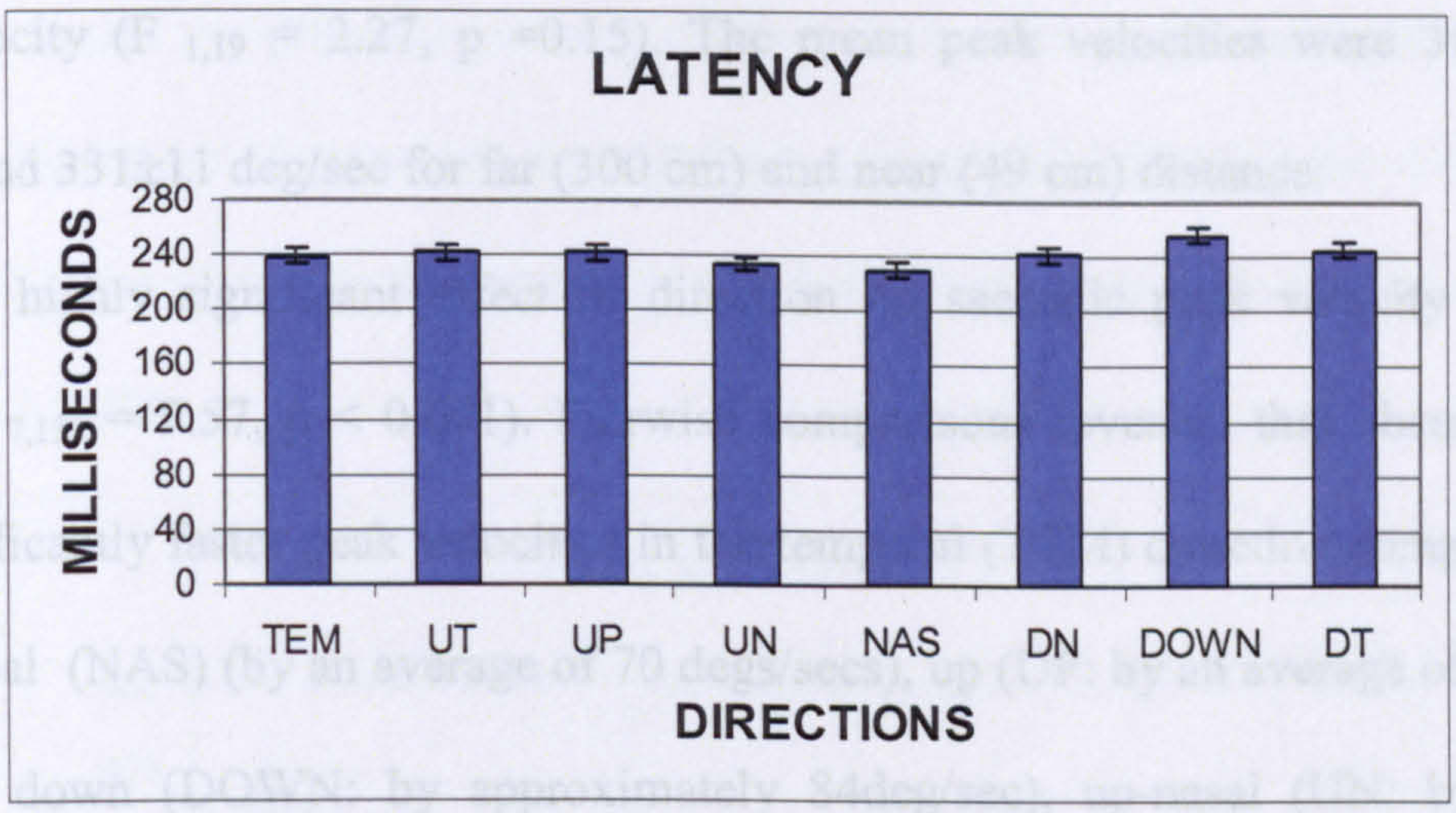


Figure 6.3.1.1: Average latency values for all observers for each direction separately when viewing distances were combined. The bars are ±1 standard error of the mean.

The interaction effect between viewing distance and direction was not significant ($F_{7, 133} = 1.595$, $p = 0.14$). This result indicates that the effect of direction on latency was similar between the two viewing distances (Figure 6.3.1.2). The error bars show standard errors of the mean.

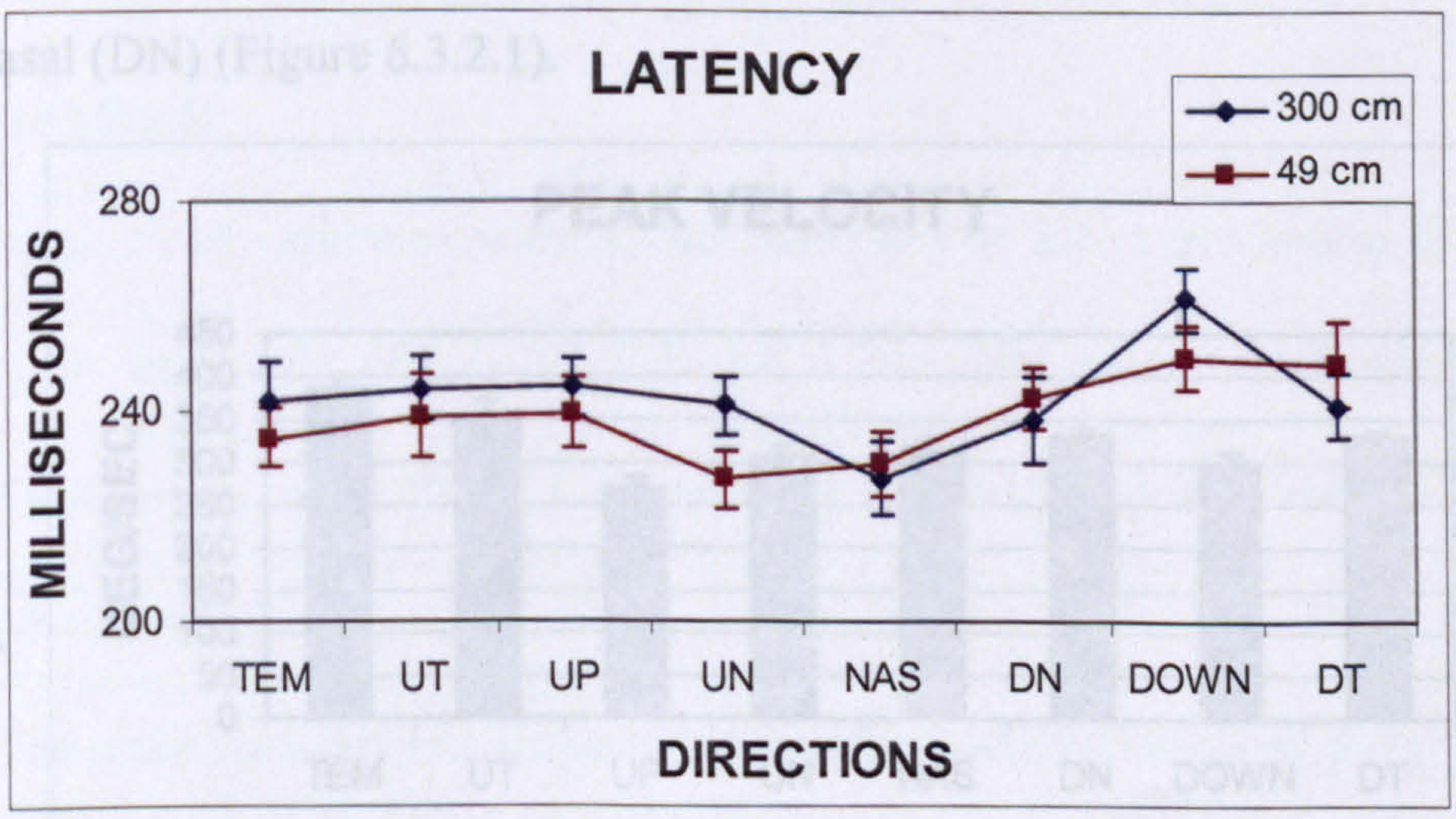


Figure 6.3.1.2: Average latency values of all observers in each direction separately and viewing distance. The blue diamonds correspond to the far data (300 cm) whereas the magenta squares corresponds to the near (49 cm). The error bars show standard error of the mean.

6.3.2 *Peak Velocity*

Analysis of variance revealed no effect of viewing distance on saccadic peak velocity ($F_{1,19} = 2.27$, $p = 0.15$). The mean peak velocities were 316±8 deg/sec and 331±11 deg/sec for far (300 cm) and near (49 cm) distance.

A highly significant effect of direction on saccadic peak velocity was found ($F_{7,133} = 9.57$, $p < 0.001$). Pairwise comparisons revealed that observers had significantly faster peak velocities in the temporal (TEM) direction compared to the nasal (NAS) (by an average of 70 degs/secs), up (UP: by an average of 114 deg/sec), down (DOWN: by approximately 84deg/sec), up-nasal (UN: by an average of 79 deg/sec), down temporal (DT: by an average of 58 deg/sec) and down nasal (DN: by an average of 55 deg/sec) directions. A similar nasal versus temporal asymmetry has been previously identified (Chapter 5) suggesting that the effect of direction (horizontal) is consistent despite differences in the observers and conditions used. In addition, saccades were significantly slower in the up (UP) direction compared to the down temporal (DT), up-temporal (UT) and down-nasal (DN) (Figure 6.3.2.1).

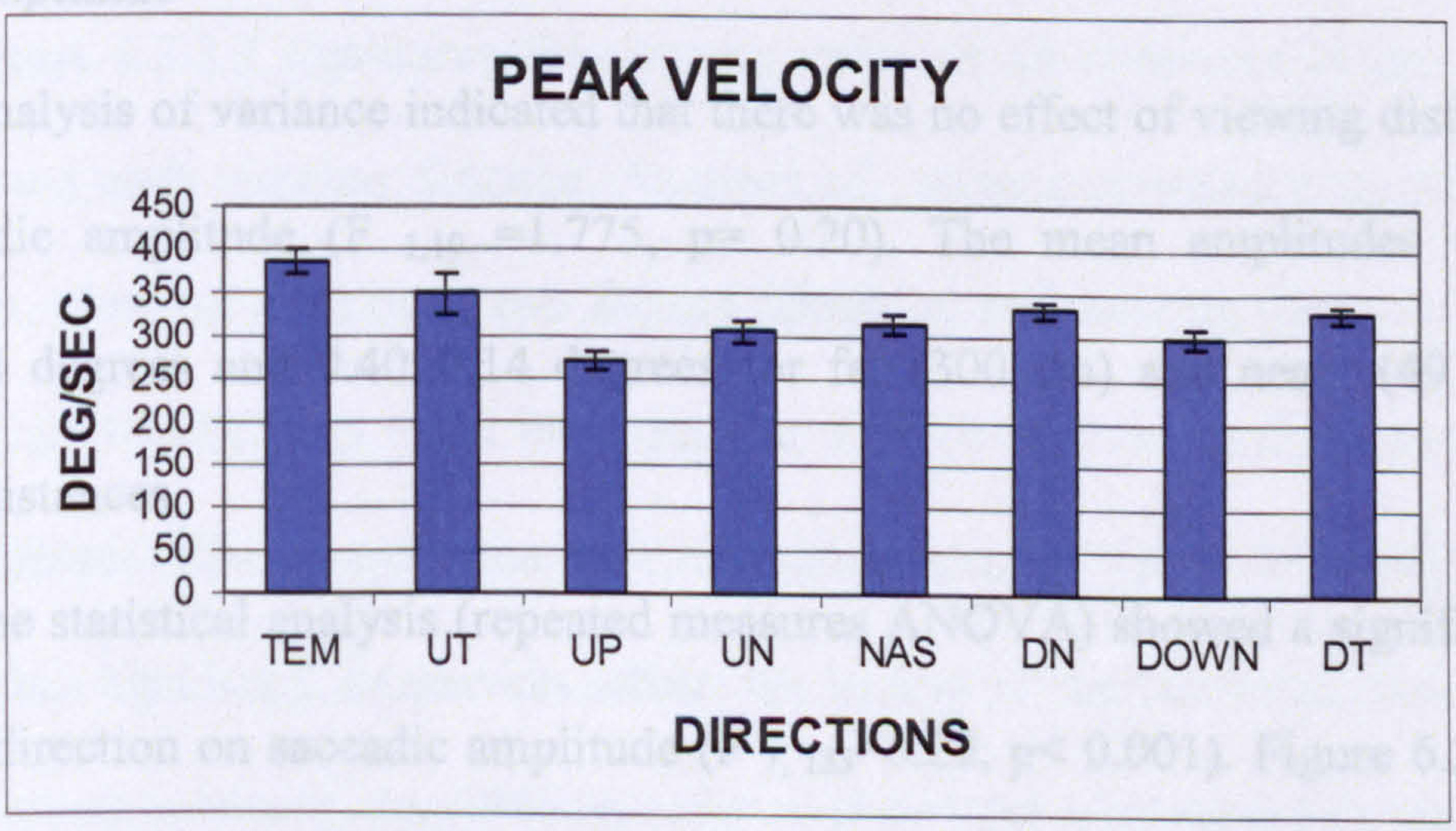


Figure 6.3.2.1: Average peak velocity values of all observers for each direction separately when both viewing distances were combined. The error bars indicate standard error of the mean.

The interaction effect of direction and viewing distances for peak velocity was not significant ($F_{7, 133} = 1.99$, p=0.61). Therefore, the way observers performed under the different viewing distances was not significantly different across the directions of gaze under investigation. Figure 6.3.2.2 shows the average peak velocity for each direction and each viewing distance respectively. The error bars are ± 1 SEM.

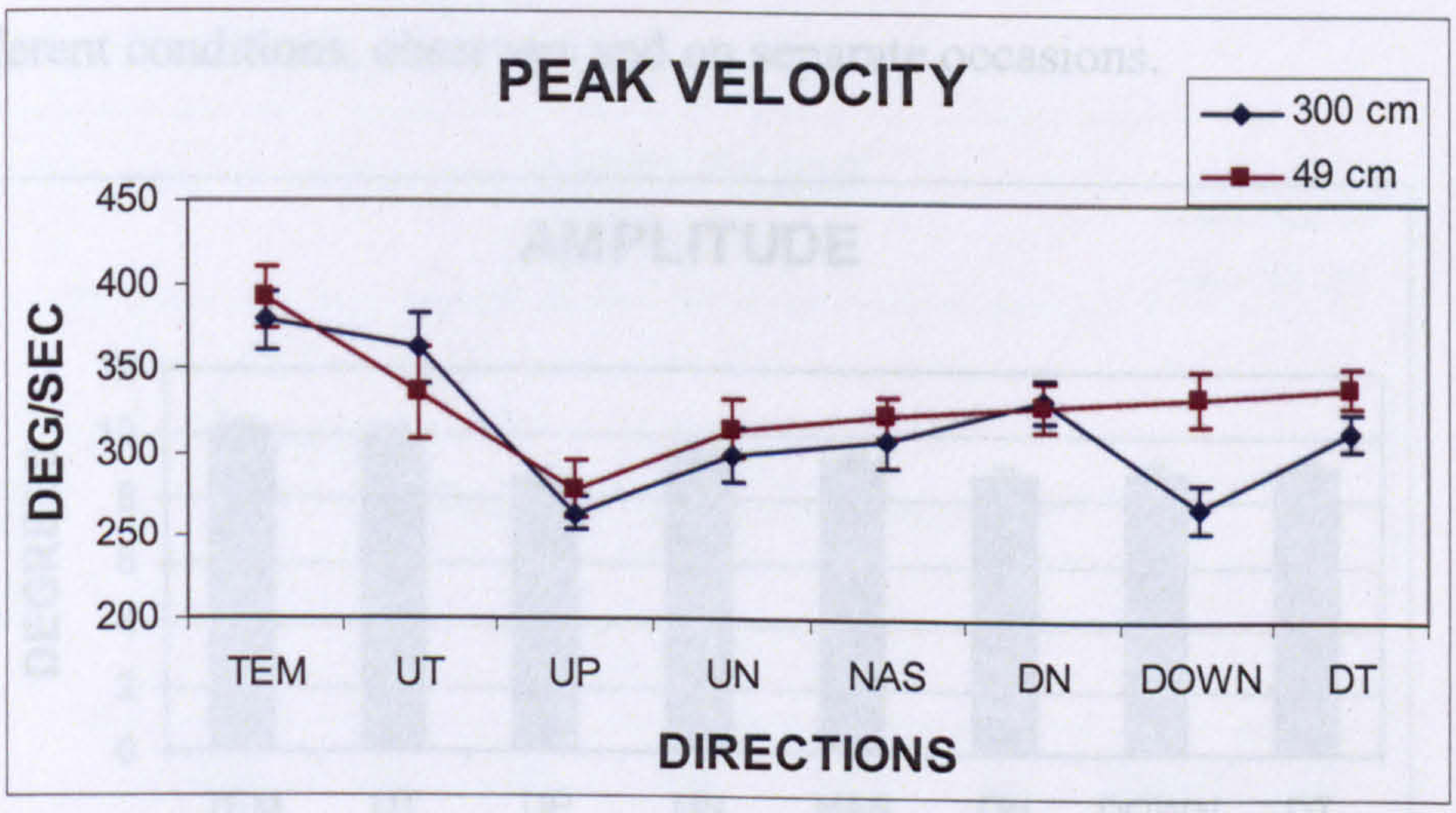


Figure 6.3.2.2: Average peak velocity values of all observers for each direction and each viewing distance. The blue diamonds correspond to the far data (300 cm) whereas the magenta squares corresponds to the near (49 cm). The error bars show standard error of the mean.

6.3.3 Amplitude

Analysis of variance indicated that there was no effect of viewing distance on saccadic amplitude ($F_{1,19} = 1.775$, p= 0.20). The mean amplitudes were 9.18±0.14 degrees and 9.40±0.14 degrees for far (300 cm) and near (49 cm) viewing distances.

The statistical analysis (repeated measures ANOVA) showed a significant effect of direction on saccadic amplitude ($F_{7, 133}=6.29$, p< 0.001). Figure 6.3.3.1 shows the average values for all observers and viewing distances for each direction. The error bars indicate ±1standard error of the mean. Planned pairwise comparisons revealed that observers had significantly larger amplitudes in the temporal (TEM) direction compared to the up (UP) direction (by an average 1.59 degrees) and those with a downward component (DN: by an average 1.40 degrees; DOWN: by an average of 1.30 degrees; DT: by an average 1.17 degrees). Similar relationships have been previously been found in section 5.3.3.2 (effect of age and direction) indicating that measurements of saccadic amplitude are repeatable even under different conditions, observers and on separate occasions.

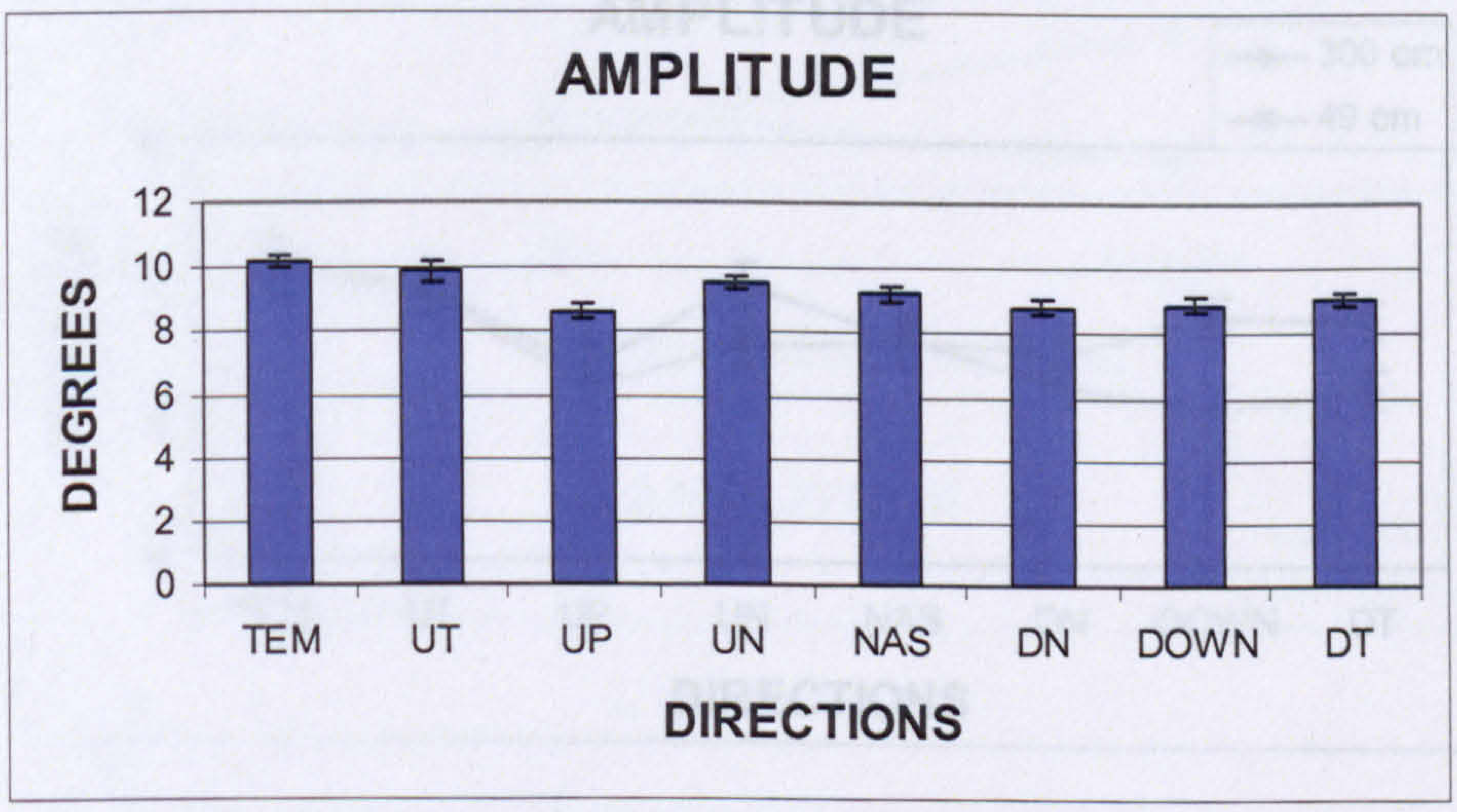


Figure 6.3.3.1: Average amplitude values of all observers for each direction separately when viewing distances combined. The bars indicate standard error of the mean.

Figure 6.3.3.2 represents the average value of all observers in the each direction and each viewing distance. Analysis of variance revealed a significant interaction effect between these two factors (direction and viewing distance) ($F_{7, 133} = 2.87$, $p = 0.008$). This result indicates that the type of viewing distance used, had a different effect across the different directions. In order to verify and interpret this significant interaction effect, we looked at the contrasts. This is a further analysis conducted by SPSS in order to reveal the level where the several interactions occurred.

The first interaction that indicated a significant result, looked at the up (UP) direction compared to down (DOWN) one when 300 cm was compared to the 49 cm viewing distance ($F_{1,19}$= 5.44, p=0.031). Another interaction that was significantly different was revealed in the comparison between the up-nasal (UN) and the down-temporal (DT) direction in the two viewing distances ($F_{1,19}$= 15.165, p= 0.001). No other interaction effect was found to be significant in the remaining directions.

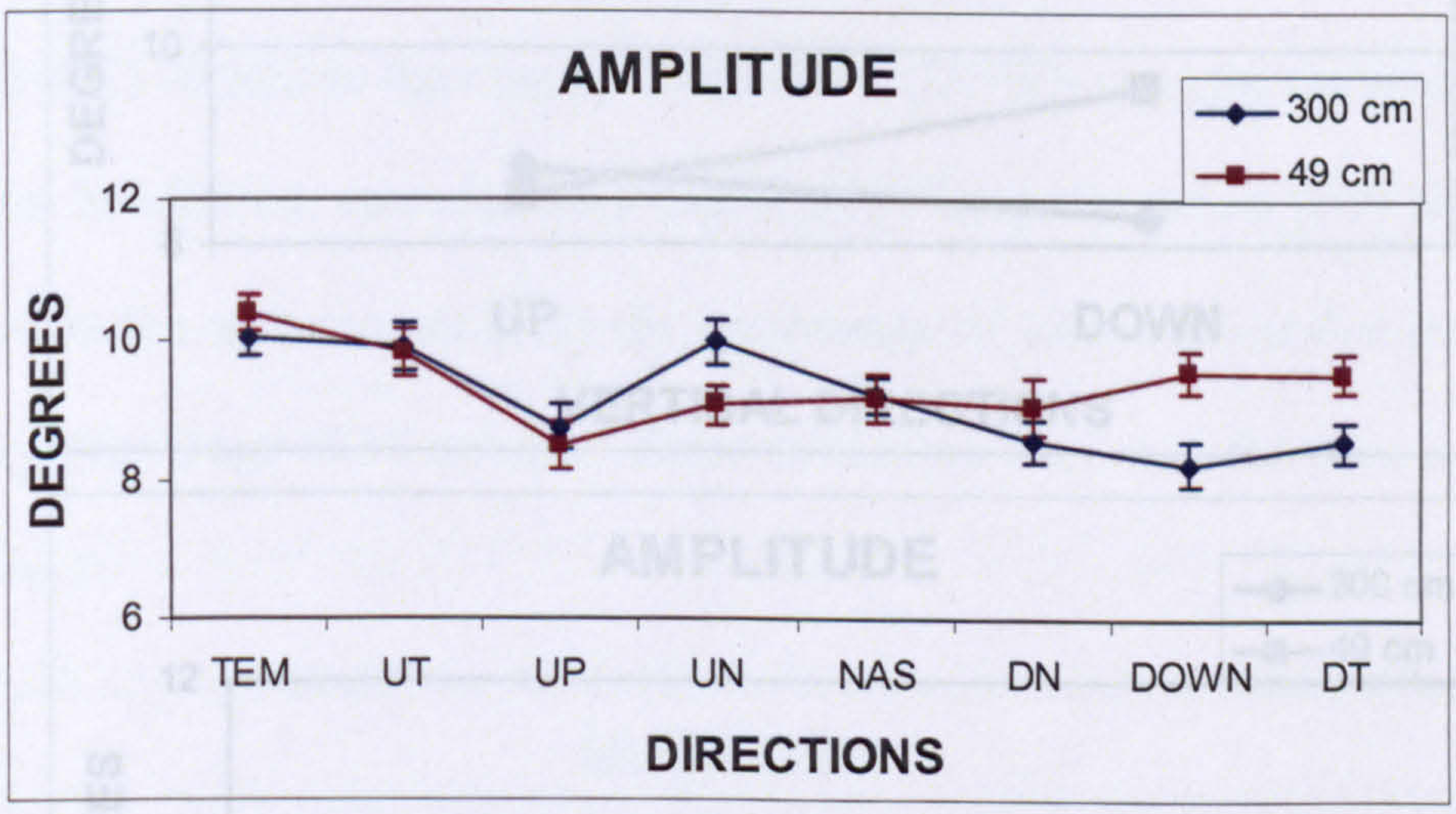


Figure 6.3.3.2: Average amplitude values of all observers for each direction separately and each viewing distance. The blue diamonds correspond to the far data (300 cm) whereas the magenta squares corresponds to the near (49 cm). The error bars show standard error of the mean.

Figure 6.3.3.3 (a) shows the average amplitude in the up and down directions and (b) in the up nasal (UN) and down temporal (DT) ones for both viewing distances (far versus near). The error bars were not included in this figure for reasons of clarity. A visual inspection of Figure 6.3.3.3 (a, b) shows non-parallel lines, which is an indication of a significant interaction effect (Field, 2000). This result suggests that observers performed differently in both viewing distances for the vertical directions and the oblique directions (UN, DT). Moreover, observers achieved larger amplitudes in the directions with a downward component (DOWN, DT) at 49 cm than the ones with an upward component (UP, UN). The reverse relationship was identified at 300 cm. Therefore these results indicate that viewing distance could have an effect in the measurements of amplitude in these four directions (UP, DOWN, UN, DT).

a)

b)

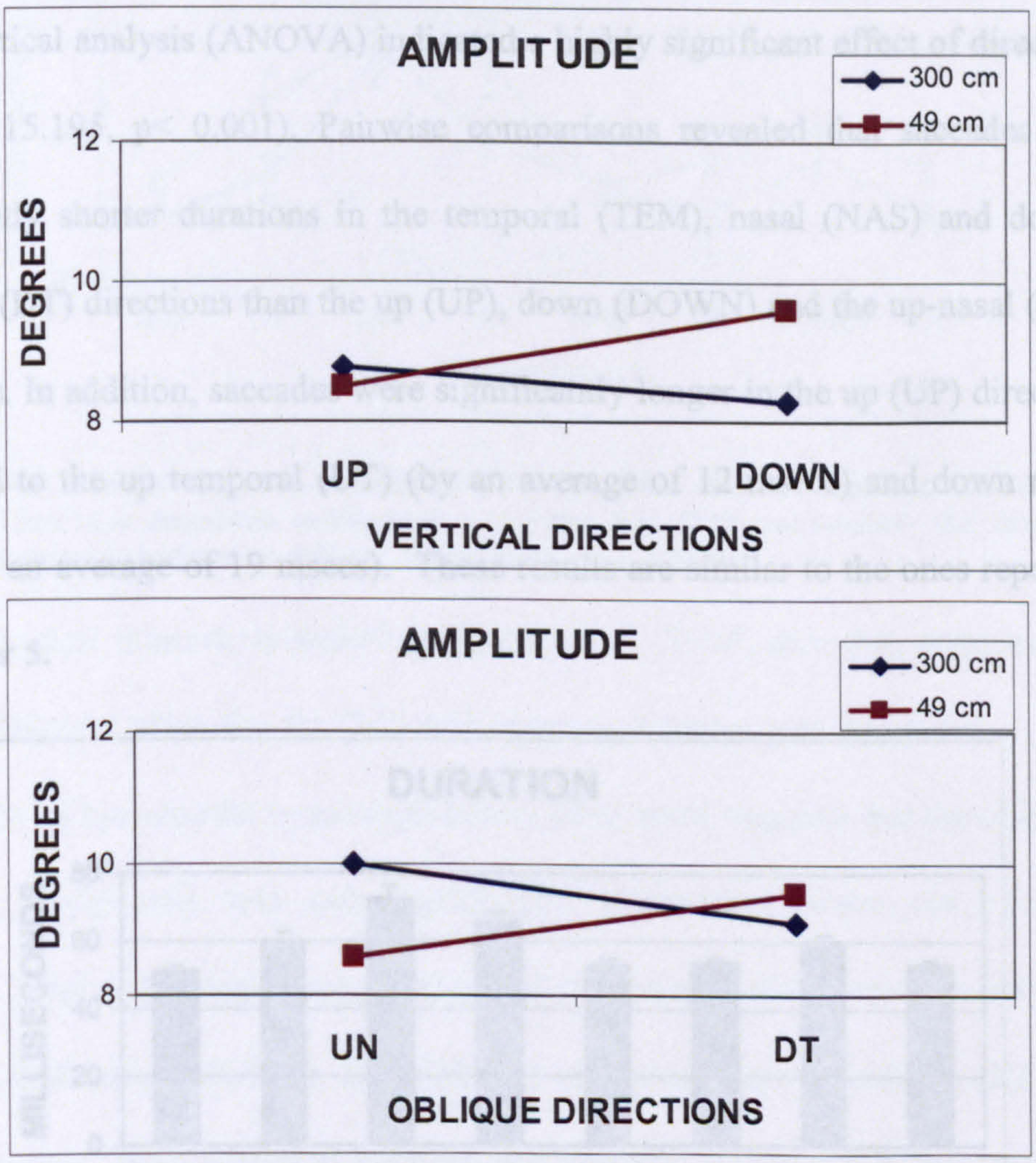


Figure 6.3.3.3: Interaction effect between the average amplitude values of each age group in (a) the UP and DOWN direction and (b) in UN and DT separately. Error bars are not displayed for reasons of clarity.

6.3.4 Duration

The analysis of variance revealed no effect of viewing distance on saccadic duration ($F_{1,19} = 3.714$, $p = 0.07$). This result suggests that the time observers needed to perform a 10° saccadic eye movement was similar across the two viewing distances under investigation. The mean duration was 57±2 msecs and 60±2 msecs for far (300 cm) and near (49 cm) distance respectively.

Figure 6.3.4.1 shows the average duration values for all observers and viewing distances for each direction. Error bars are ±1 standard error of the mean. The statistical analysis (ANOVA) indicated a highly significant effect of direction ($F_{7,133}$= 15.195, p< 0.001). Pairwise comparisons revealed that saccades had significantly shorter durations in the temporal (TEM), nasal (NAS) and down-temporal (DT) directions than the up (UP), down (DOWN) and the up-nasal (UN) directions. In addition, saccades were significantly longer in the up (UP) direction compared to the up temporal (UT) (by an average of 12 msecs) and down nasal (DN) (by an average of 19 msecs). These results are similar to the ones reported in Chapter 5.

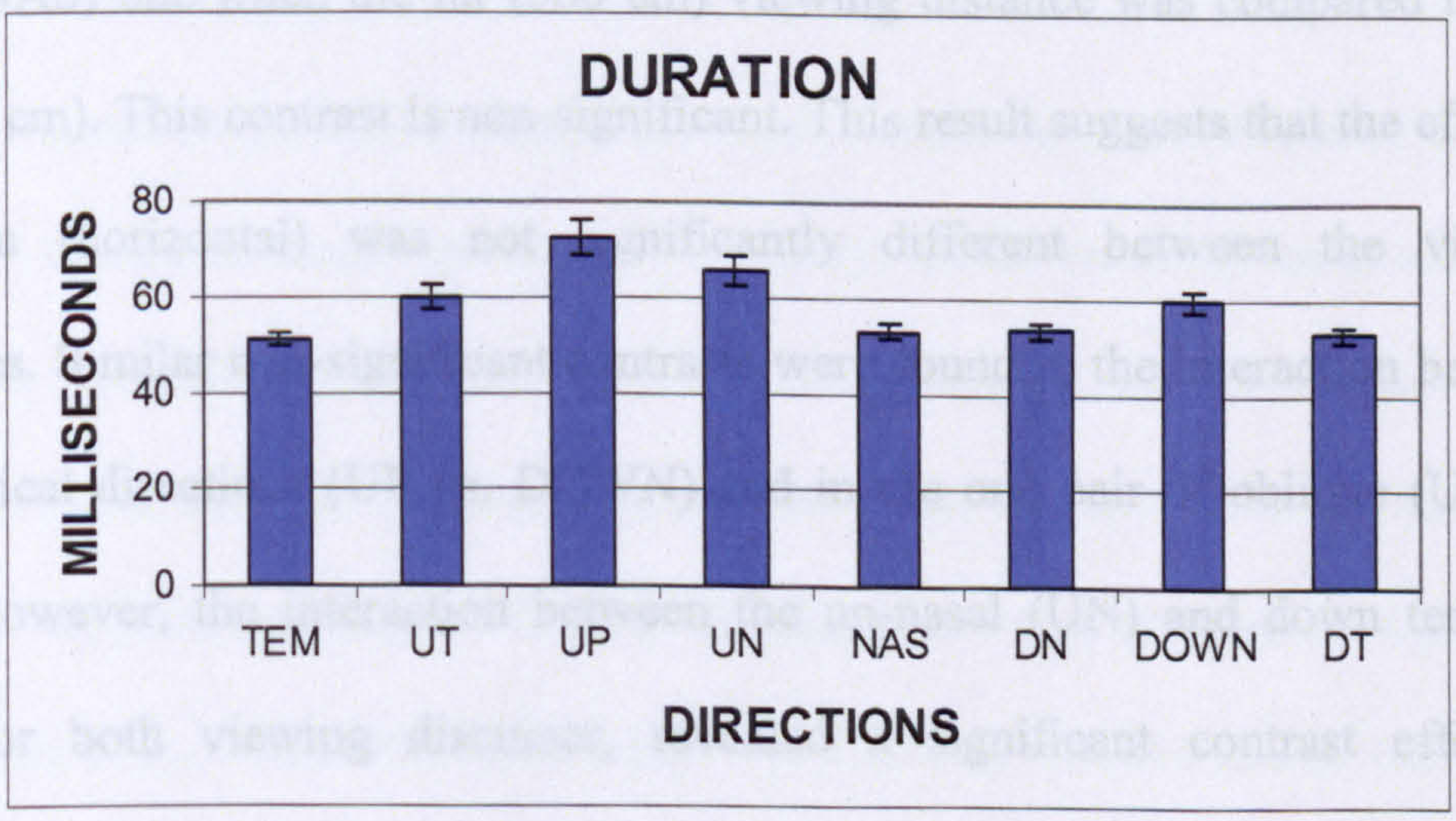


Figure 6.3.4.1: Average duration values of all observers for each direction separately when viewing distances combined. The bars indicate standard error of the mean.

Analysis of variance revealed a significant interaction effect between the directions and viewing distances ($F_{7,133}$ = 5.12, p< 0.001). Figure 6.3.4.2 shows the average duration value of all observers for each viewing distances and direction. Error bars show ±1 standard error of the mean.

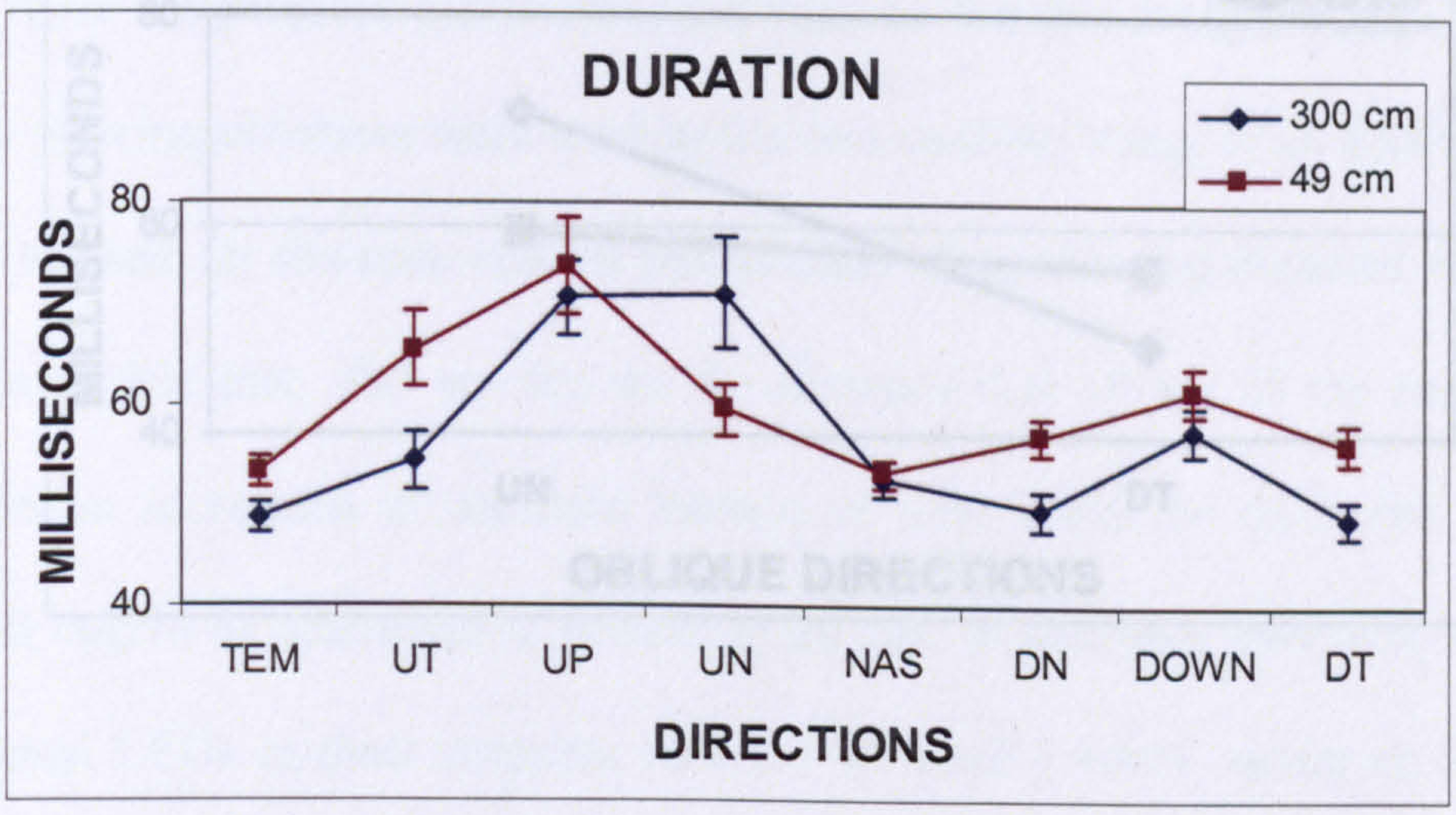


Figure 6.3.4.2: Average duration values of all observers for each viewing distance and the directions. The blue diamonds correspond to the far data (300 cm) whereas the magenta squares corresponds to the near (49 cm). Error bars are ±1SEM.

The first interaction looked at the temporal (TEM) direction compared to nasal (NAS) one when the far (300 cm) viewing distance was compared to near one (49 cm). This contrast is non-significant. This result suggests that the effect of direction (horizontal) was not significantly different between the viewing distances. Similar non-significant contrasts were found in the interaction between the vertical directions (UP vs. DOWN) and in the one pair of oblique (UT and DN). However, the interaction between the up-nasal (UN) and down temporal (DT) for both viewing distances, revealed a significant contrast effect ($F_{1,19}$=10.63, p= 0.004). This result suggests that the variation in amplitude within these oblique directions (UN, DT) was significantly different for each viewing distance (Figure 6.3.4.3). Therefore viewing distance could have an effect in the measurements of duration in these two oblique directions (UN, DT).

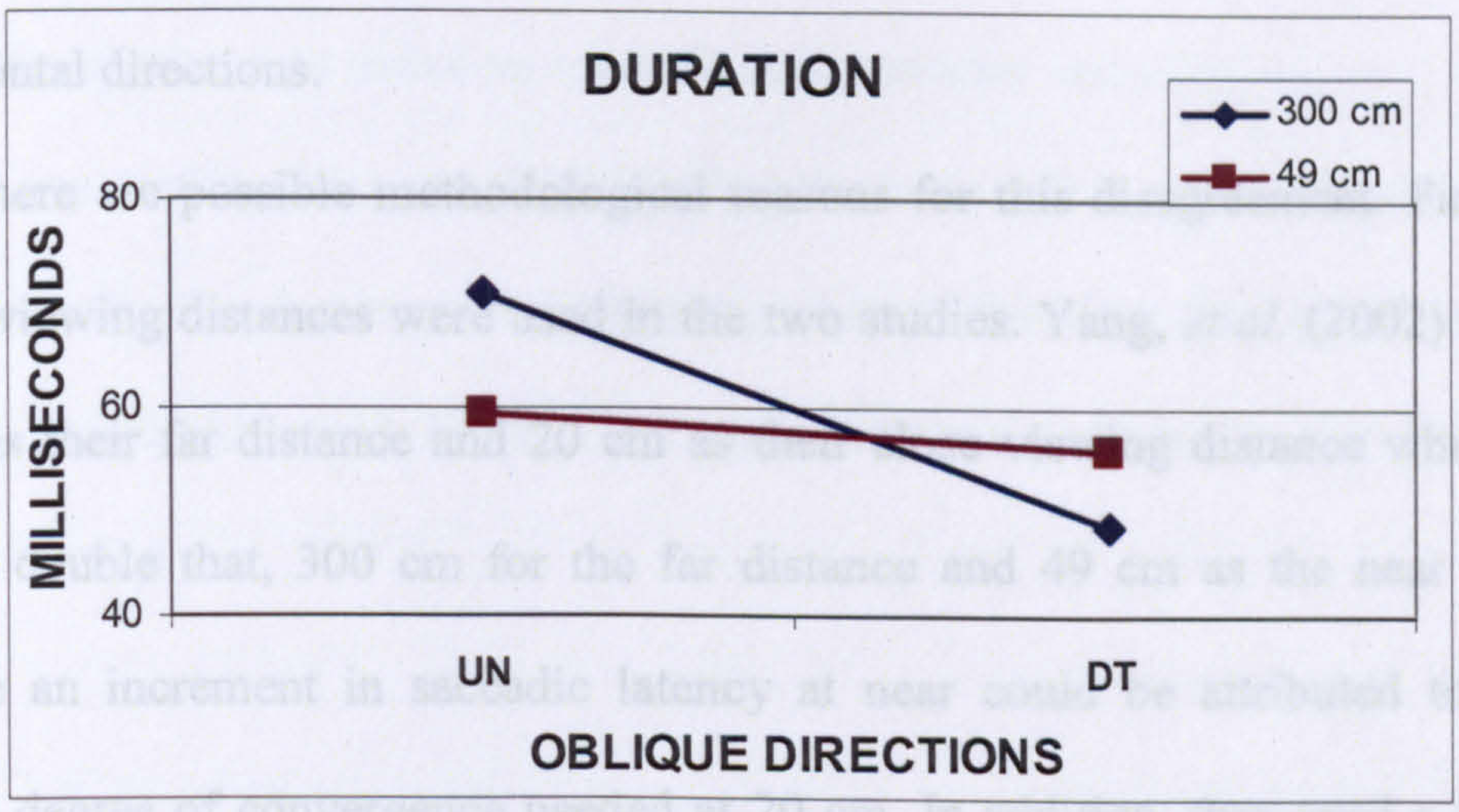


Figure 6.3.4.3: Interaction effect between average duration values of each age group in the up nasal (UN) and down temporal (DOWN) direction separately. The blue diamonds correspond to the far data (300 cm) whereas the magenta squares corresponds to the near (49 cm). Crossed lines indicate a significant interaction effect. Error bars are not displayed for reasons of clarity.

6.4 Discussion

The results from this study show that there is no main effect of viewing distance on the saccadic parameters (latency, peak velocity, amplitude and duration). However, conflicting results were found on the interaction effect between directions and viewing distances for saccadic amplitude and duration. For the saccadic amplitude the pair of directions that showed a significant interaction effect were the vertical (UP vs. DOWN) directions and one set of oblique (UN versus the DT) ones. For the saccadic duration, this significant interaction effect was limited to a pair of oblique directions (UN versus the DT).

This investigation has produced results that appear to contradict those of Yang, *et al.* (2002). They reported that saccadic latencies at close distance were shorter by approximately 20 msecs than that at far in both adults and children in the horizontal directions.

There are possible methodological reasons for this disagreement. Firstly, different viewing distances were used in the two studies. Yang, *et al.* (2002) used 150 cm as their far distance and 20 cm as their close viewing distance whereas ours was double that, 300 cm for the far distance and 49 cm as the near one. Therefore an increment in saccadic latency at near could be attributed to the increased degree of convergence needed at 20 cm. In addition, they used a three dimensional LEDs as their stimulus whereas we used a white square on a black background. Yang, *et al.* (2002) suggested that the increased latencies at near when compared to far could be explained by the increased angular size and change in luminance of their stimulus at near viewing distance. In contrast, the visual angle and luminance level of our stimulus remained constant during both viewing distances (far versus near). There is also the possibility that the different recording methods contributed to differences in the results. They recorded binocular horizontal eye movements with a photoelectric device whereas we recorded monocular eye movements in all directions of gaze with an infrared eye tracker. As a consequence, the way they obtained the saccadic signal (averaging the position signal of the two eyes) might have introduced changes in the saccadic latency values obtained.

Our results on the effect of viewing distance on saccadic amplitude agree to those reported by Yang and Kapoula (2003). They reported that the viewing distance (far versus near) does not have an effect on the accuracy of the saccades in adults and children. To date, there are no known studies on how changes of viewing distance have an effect on saccadic peak velocity and duration.

In conclusion, these results show that the main effect of viewing distance in the saccadic eye movements is non-significant therefore this non-invasive recording technique could be applied more conveniently using the smaller working distance.

CHAPTER 7:

The effect of defocus on saccadic eye movements.

7.1 Introduction

Saccadic eye movements are becoming a common research tool in different clinical environments due to their easily measurable dynamic properties (see Leigh and Kennard, 2004 for a review). However, optical defocus is commonly encountered in a clinical environment. As such the potential effect it may have on the dynamics of saccadic eye movements should be understood.

To date, there are no known studies on the effect of different levels of defocus on the four saccadic parameters investigated in this thesis (latency, peak velocity, amplitude and duration). However, Ukwade and Bedell (1993) investigated the effect of dioptric blur (0.00DS, +1.00DS, +2.00DS and +4.00DS) on the stability of binocular fixation. Using an infrared technique, they reported that binocular fixation stability was worse when subjects were blurred by +2.00 or +4.00DS compared to 0.00DS dioptres blur. They concluded that the recordings of eye movements in a clinical environment should not be affected by residual refractive errors as long as they are within usual ranges (less than +1.00 DS).

In contrast, Steinman *et al.* (2003) reported that accurate fixation occurs in order to see finer details of the visual display and not as a result of being able to see them. In their study, a magnetic search coil technique was used. Three observers [two presbyopes and one low myope (-0.70 DS)] worn more positive power contact lenses (+5.00DS, +6.50DS and +3.50DS) to improve or worsen their vision at the near viewing distance. When vision was worsened by the contact lenses, fixation stability subsequently improved. Therefore, the authors concluded that if fixation stability is important for the task, then reducing the quality of the visual display might be helpful. In contrast to Ukwade and Bedell (1993), these findings suggest that dioptric blur (i.e. reduced visibility of a target) may result in more accurate saccadic eye movements.

From the above, studies that have investigated the effect of defocus on eye movements are limited and provide conflicting results. If saccadic eye movement parameters are recorded in a clinical environment then it is essential to understand the extent to which refractive error needs to be corrected. Therefore, the aim of this study is to investigate the potential effect of defocus on the characteristics of saccadic eye movements.

7.2 Methods

7.2.1 Eye movement apparatus/ Stimulus / Recording System

The monitoring apparatus (IRIS 6500), stimulus and recording system (laptop running LABVIEW 6.1) are the same as those described previously in Chapters three and four.

7.2.2 Observers

Twenty visually normal observers were recruited from the staff and student population of University of Bradford in order to participate in this study. Their ages ranged from 20 to 39 years (median 25.5 years). Thirteen of the subjects were female.

7.2.3 Experimental procedure / Data processing

The same experimental procedure was followed in this study as the one described in Chapter four. Monocular recordings of 10-degree saccadic eye movements in eight different directions of gaze (TEM, NAS, UP, DOWN, UN, DT, UT, DN) were collected. All measurements were repeated for all the levels of defocus. The data processing in this study is identical to the one described in Chapter four.

7.2.4 Level of Defocus

A pilot study involving two young observers (CH and MB) was carried out in order to determine the most appropriate levels of defocus. Three levels of defocus (+0.50DS, +1.00DS, and +2.00DS) were used for each of the eight directions. The level of defocus was randomized and the observers were unaware of the level of defocus used.

Analysis provided individual values for each saccadic parameter (latency, duration, peak velocity and amplitude) in all of the eight directions and all three levels of defocus (0.50DS, +1.00DS, and +2.00DS). We also calculated the average and standard deviation (STDEV) obtained from four repeated measurements for each subject. This pilot data were not analysed statistically due to the small number of observers.

Figures 7.2.4.1 – 7.2.4.4 show the average values for each observer and each direction for the four different parameters (latency, peak velocity, amplitude and duration). The error bars are ±1 standard deviation (STDEV). A visual inspection of these figures does not reveal any consistent effect of the different levels of defocus for the four parameters. In addition, there is no consistent difference in the values measured for the two observers.

Due to this lack of effect for defocus up to 2.00DS, we collected data from one of the observers (CH) with a +4.00DS level of defocus in the oblique directions (UT, DN, UN, DT). These directions were chosen because they have shown the highest variability when compared to the horizontal and vertical directions in previous recordings.

Figure 7.2.4.5 shows the average saccadic latency (obtained from four repeated individual measurements) using different levels of defocus. This figure reveals that even a higher level of defocus (+4.00DS) does not have any effect on latency in the oblique directions.

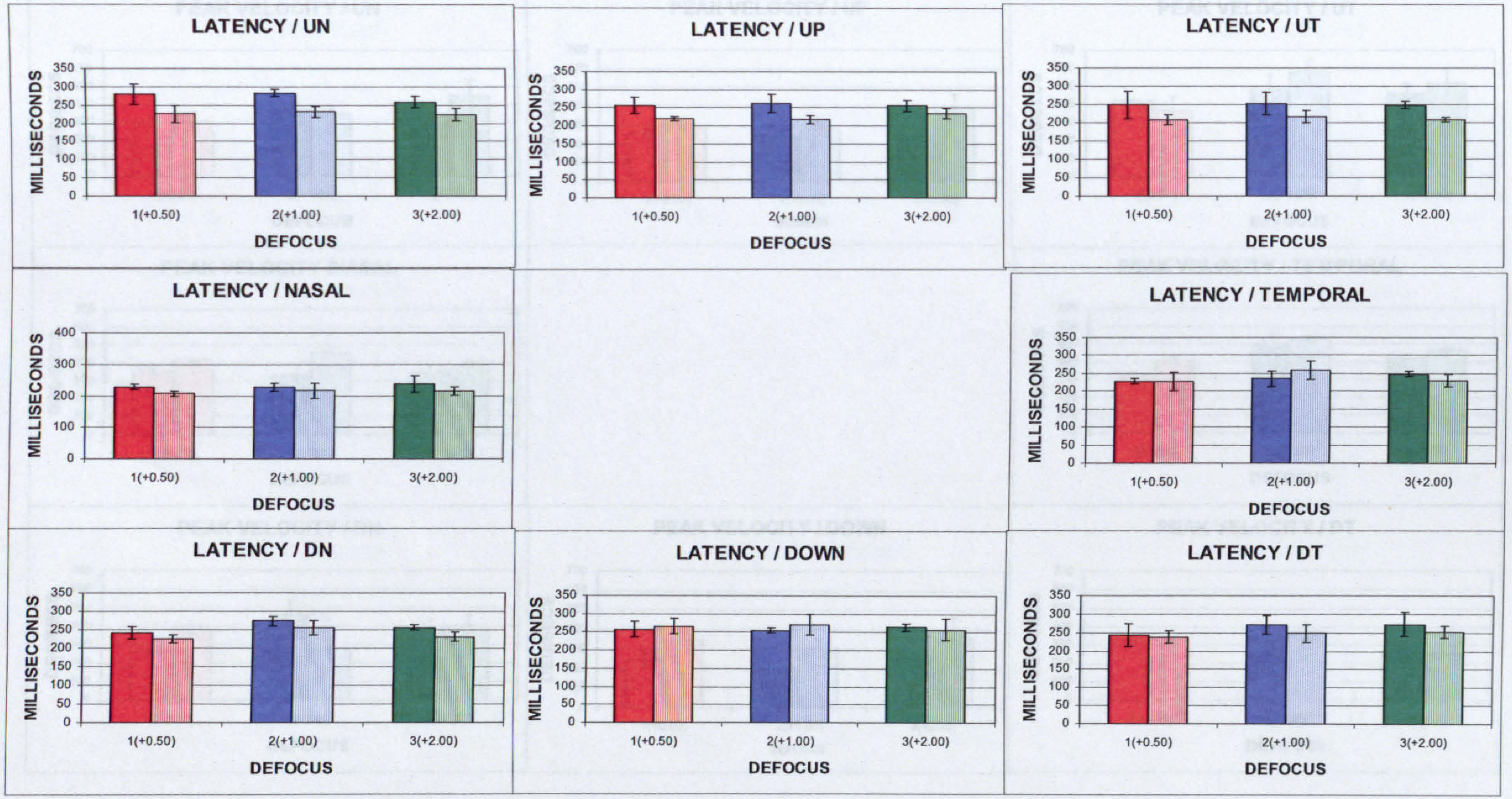


Figure 7.2.4.1: Average values of saccadic latencies obtained from 4 individual measurements in the 8 directions under investigation. Filled columns show the data from CH whereas the striped columns show the data from MB. The error bars are ±1 standard deviation.

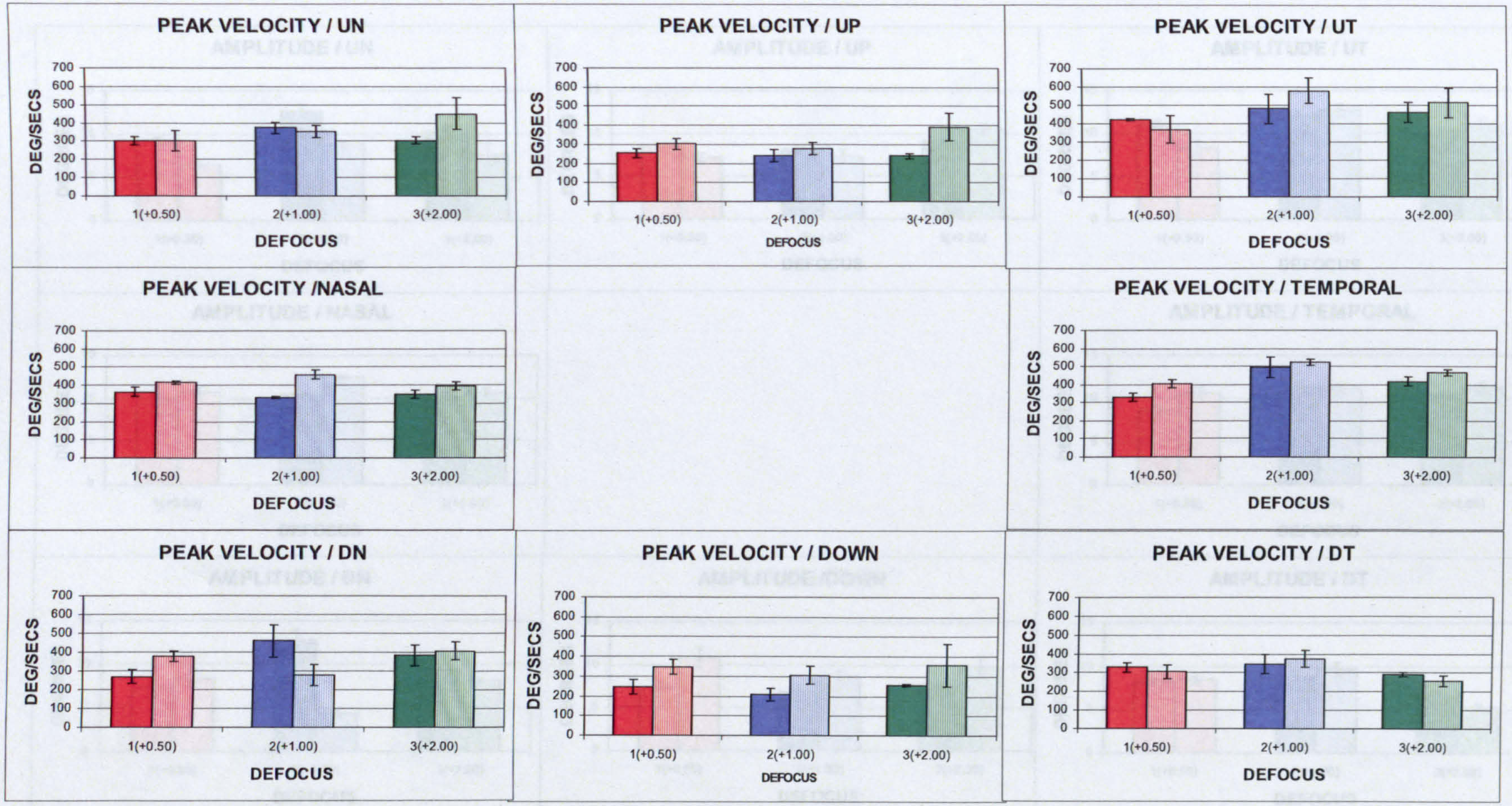


Figure 7.2.4.2: Average values of saccadic peak velocities obtained from 4 individual measurements in the 8 directions under investigation. Filled columns show the data from CH whereas the striped columns show the data from MB. The error bars show ±1 standard deviation.

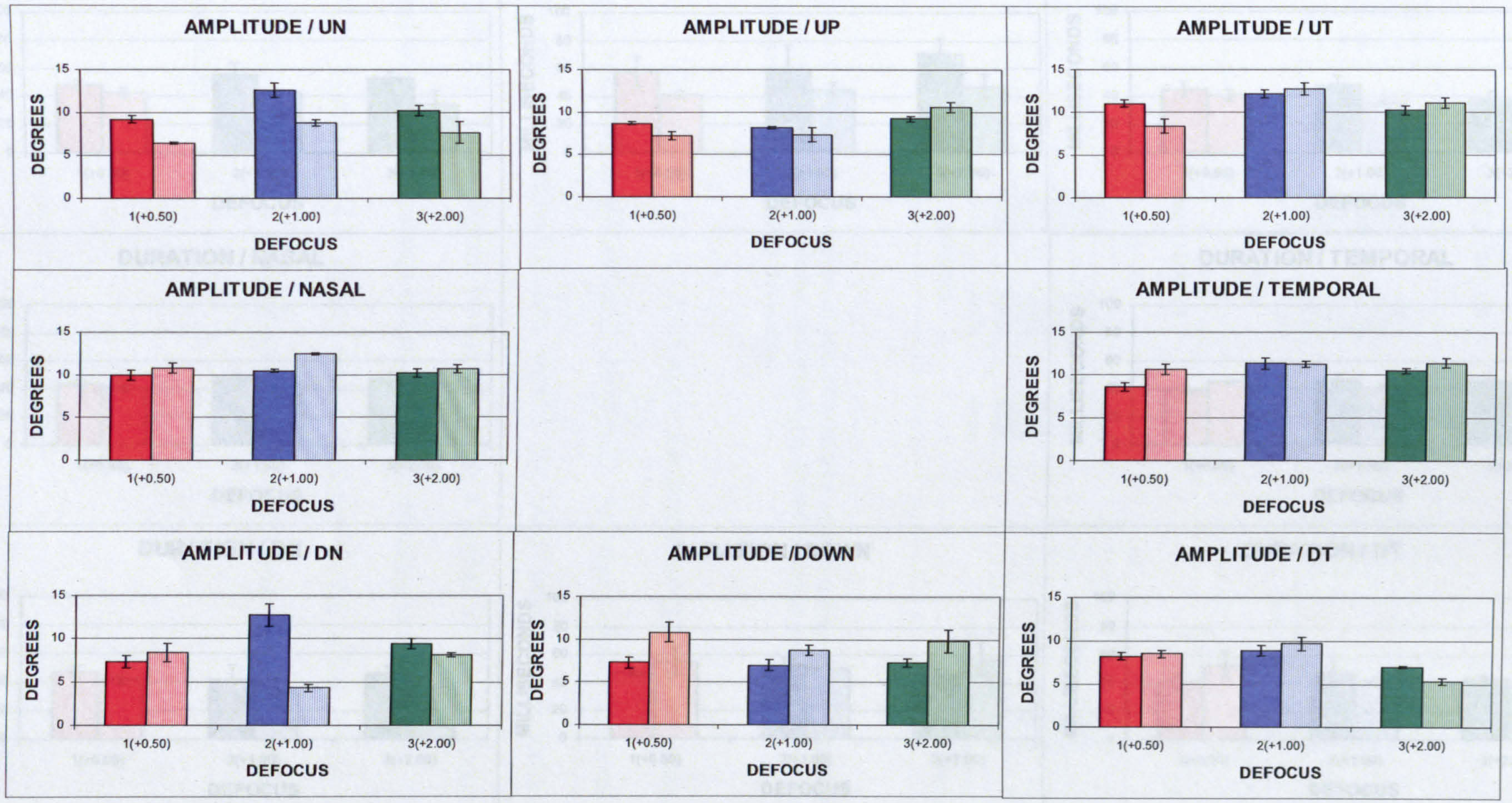


Figure 7.2.4.3: Average values of saccadic amplitudes obtained from 4 individual measurements in the 8 directions under investigation. Filled columns show the data from CH whereas the striped columns show the data from MB. The error bars show ±1 standard deviation.

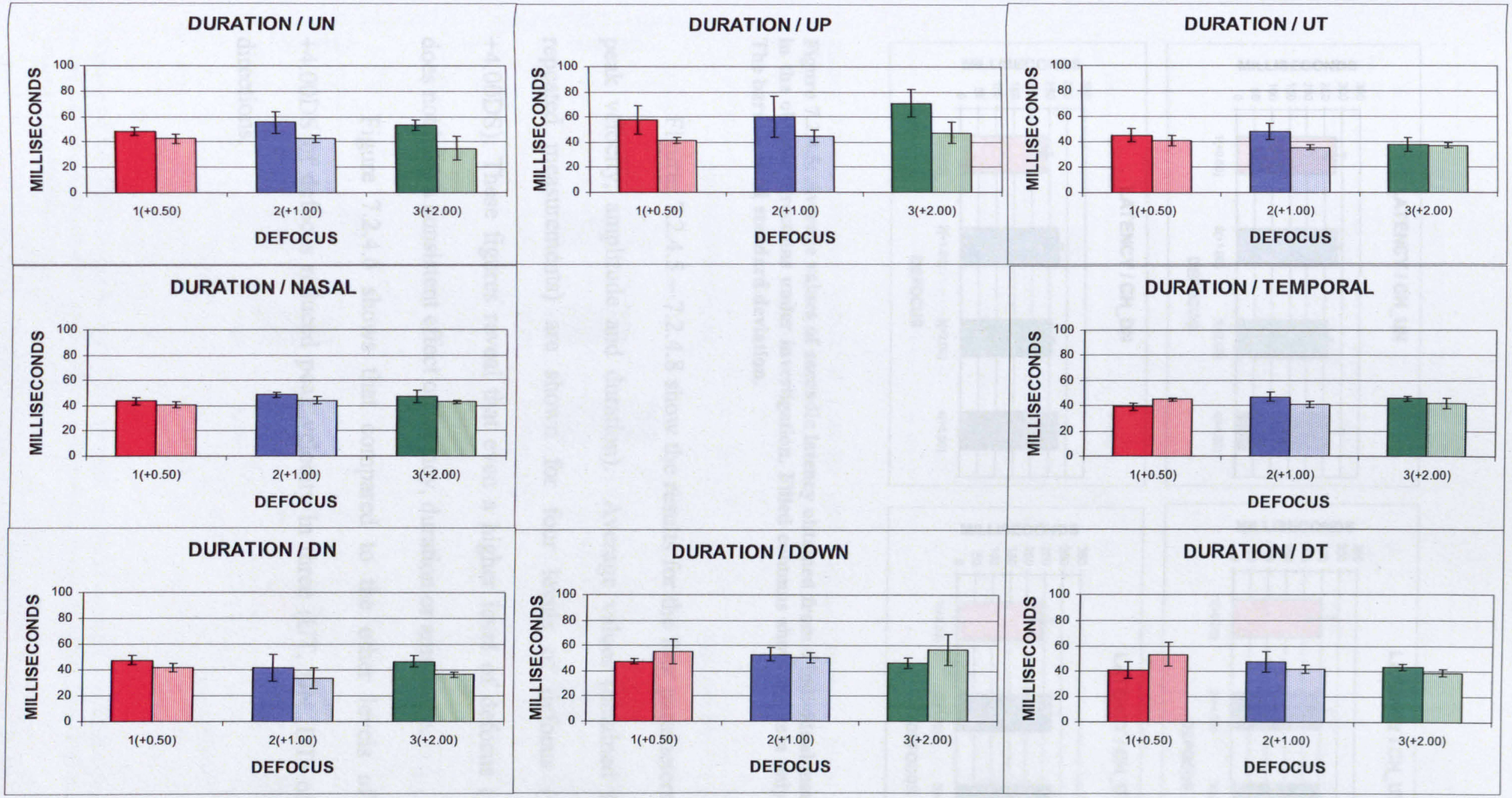


Figure 7.2.4.4: Average values of saccadic durations obtained from 4 individual measurements in the 8 directions under investigation. Filled columns show the data from CH whereas the striped columns show the data from MB. The bars show ±1 standard deviation.

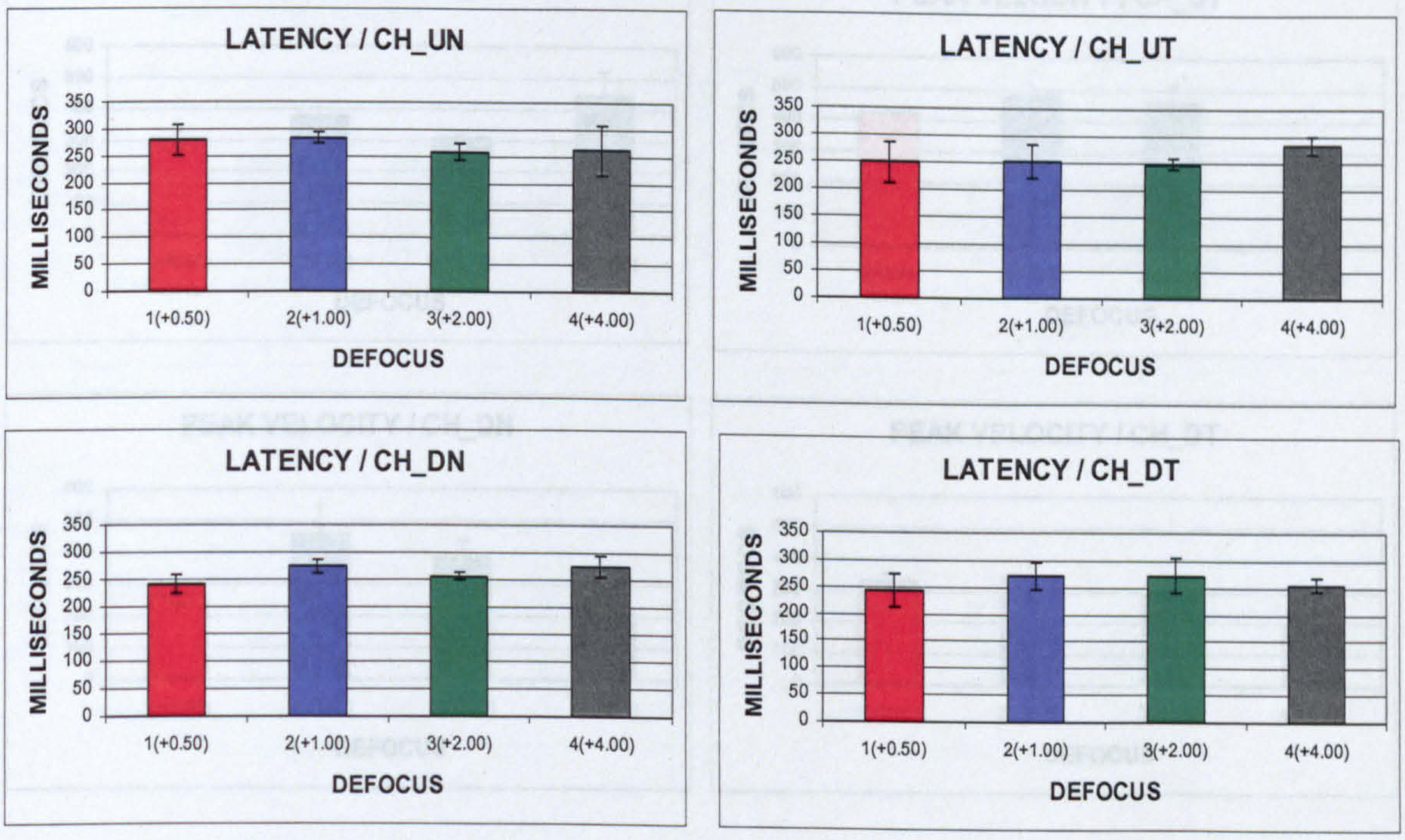


Figure 7.2.4.5: Average values of saccadic latency obtained from 4 individual measurements in the oblique directions under investigation. Filled columns show the data only from CH. The bars show ±1 standard deviation.

Figures 7.2.4.5 – 7.2.4.8 show the results for the four parameters (latency, peak velocity, amplitude and duration). Average values (obtained from four repeated measurements) are shown for four levels of defocus (+0.50DS-+4.00DS). These figures reveal that even a higher level of defocus (+4.00DS) does not have a consistent effect on latency, duration or amplitude.

Figure 7.2.4.6 shows that compared to the other levels of defocus, +4.00DS of defocus reduced peak velocity in three (UT, DN, DT) of the four directions.

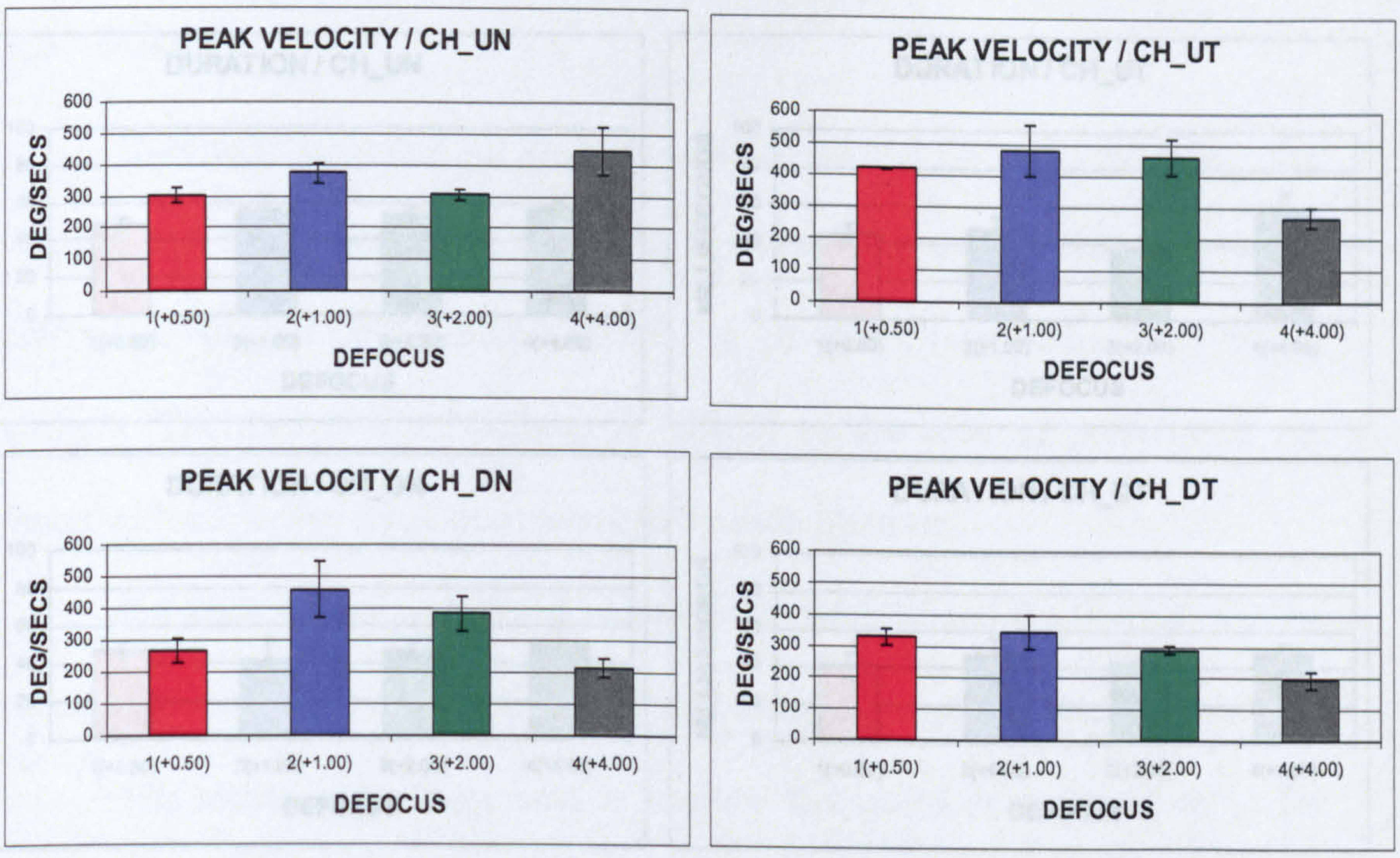


Figure 7.2.4.6: Average values of saccadic peak velocity obtained from 4 individual measurements in the oblique directions under investigation. Filled columns show the data only from CH. The bars show ±1 standard deviation

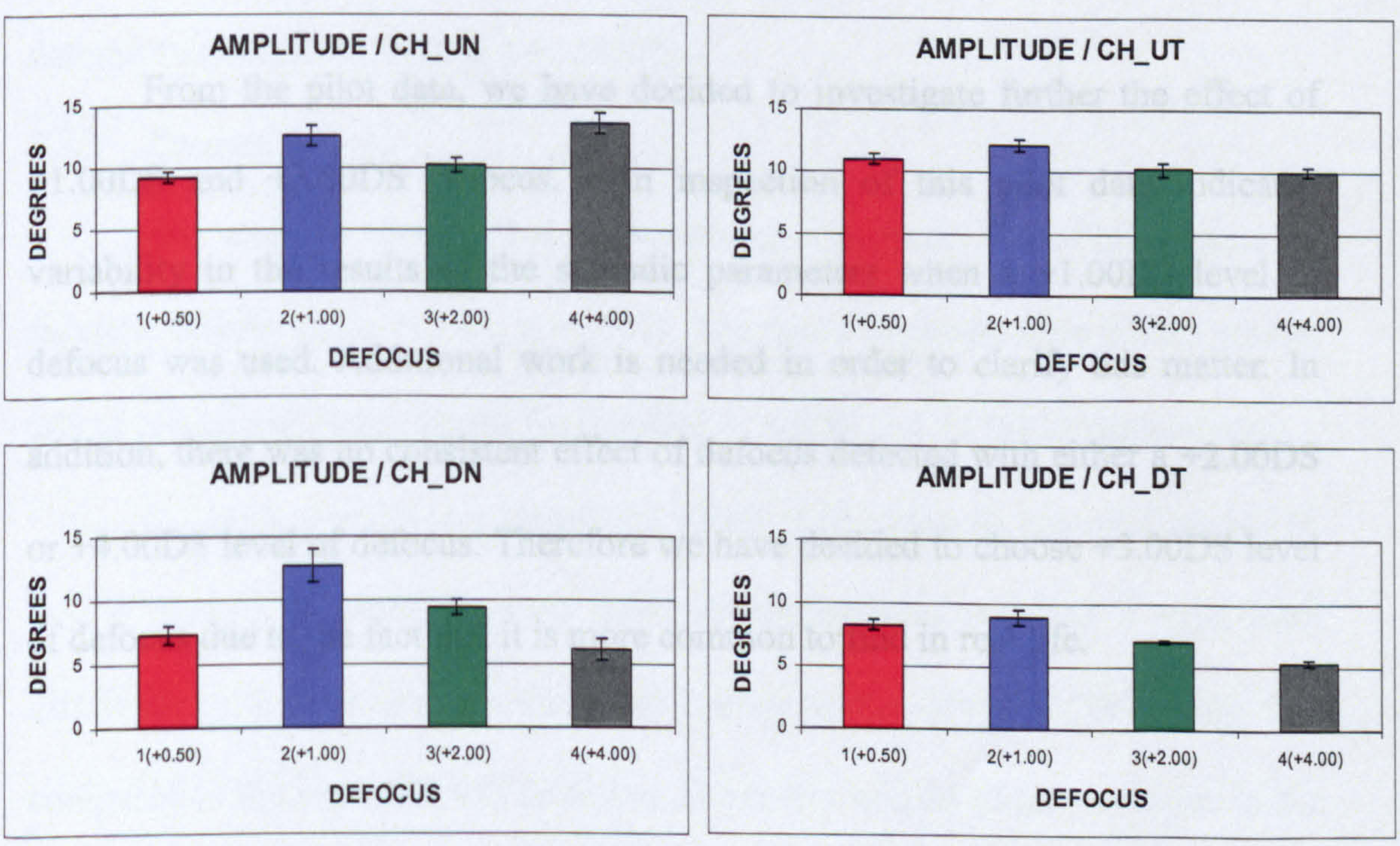


Figure 7.2.4.7: Data from observer CH. Average values of saccadic amplitude obtained from 4 individual measurements in the oblique directions under investigation. The bars show ±1 standard deviation.

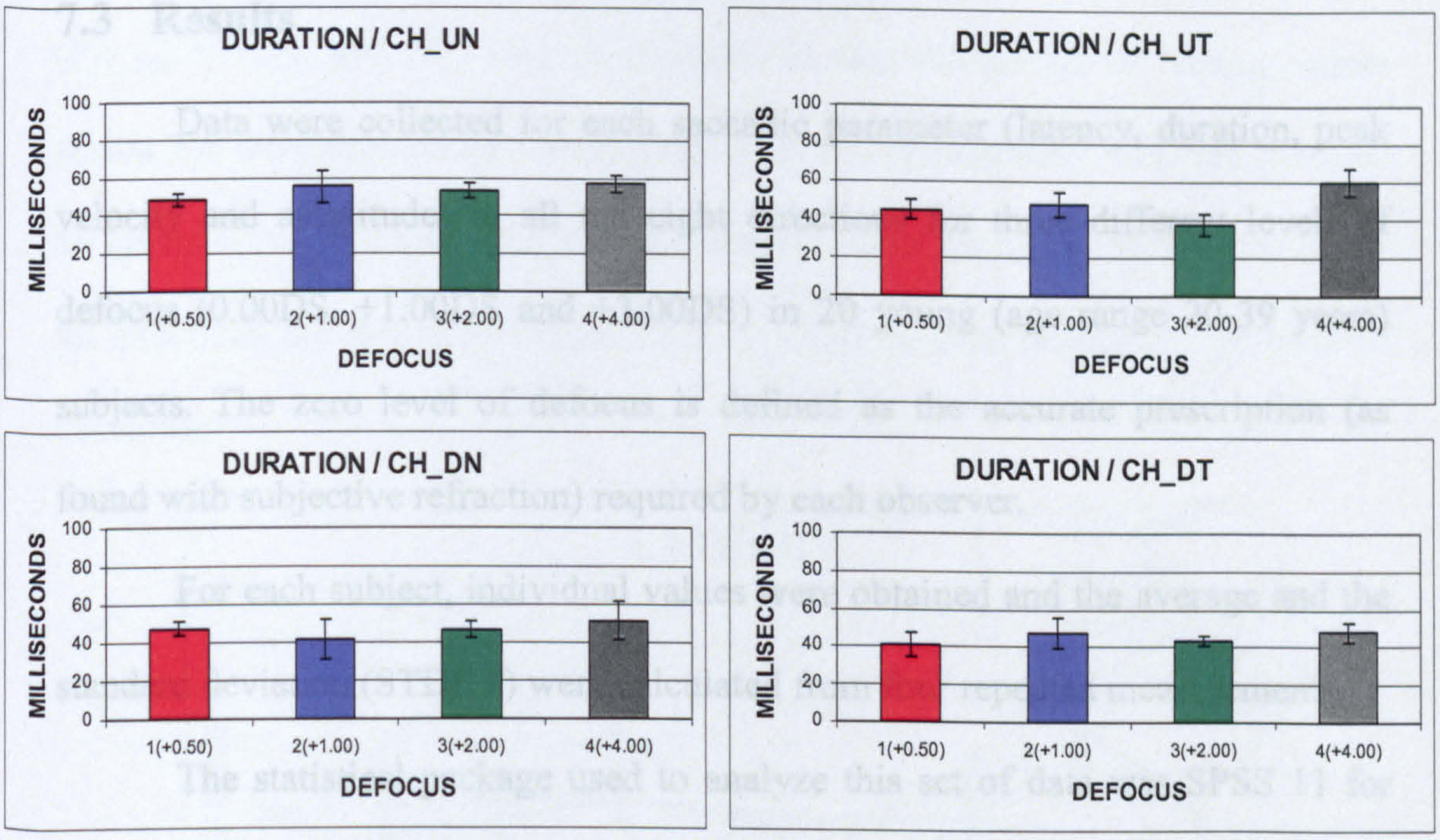


Figure 7.2.4.8: Average values of saccadic duration obtained from 4 individual measurements in the oblique directions under investigation. Filled columns show the data only from CH. The error bars show ±1 standard deviation.

From the pilot data, we have decided to investigate further the effect of +1.00DS and +3.00DS defocus. An inspection of this pilot data indicated variability in the results of the saccadic parameters when a +1.00DS level of defocus was used. Additional work is needed in order to clarify this matter. In addition, there was no consistent effect of defocus detected with either a +2.00DS or +4.00DS level of defocus. Therefore we have decided to choose +3.00DS level of defocus due to the fact that it is more common to find in real life.

7.3 Results

Data were collected for each saccadic parameter (latency, duration, peak velocity and amplitude) in all the eight directions for three different levels of defocus (0.00DS, +1.00DS and +3.00DS) in 20 young (age range 20-39 years) subjects. The zero level of defocus is defined as the accurate prescription (as found with subjective refraction) required by each observer.

For each subject, individual values were obtained and the average and the standard deviation (STDEV) were calculated from four repeated measurements.

The statistical package used to analyze this set of data was SPSS 11 for Windows. A repeated measures ANOVA was applied for each saccadic parameter (latency, peak velocity, amplitude and duration) separately. The within-subject factors were direction (TEM, NAS, UP, DOWN, UT, DN, UN, DT) and level of defocus (0.00DS, +1.00DS and +3.00DS).

7.3.1 Latency

Our analysis reveals that there was no-significant effect of defocus on saccadic latency ($F_{2,38} = 2.81$, $p = 0.07$). The mean latencies were 242±5 msecs, 243±4 msecs and 249±4 msecs for 0.00DS, +1.00DS and +3.00DS respectively.

However, there was a significant effect of direction on saccadic latency ($F_{7,133} = 3.79$, $p = 0.001$). Planned pairwise comparisons revealed a significant difference ($p=0.042$) between the mean latency of the down (DOWN) direction compared to the nasal (NAS) direction. Observers needed longer latencies in the down direction by approximately 20 msecs when compared to the nasal. A similar result was also observed previously in section 6.3.1.2, where observers had longer latencies in the down direction by an average of 25 msecs.

The interaction effect between defocus and direction was not significant ($F_{14,\ 266}$ = 1.39, p=0.16). This result indicates that the pattern of latency values across the directions under investigation was not significantly different between all levels of dioptric blur. The average latency values for all levels of defocus and all directions are shown in Figure 7.3.1.1. Error bars show ±1 standard error of the mean.

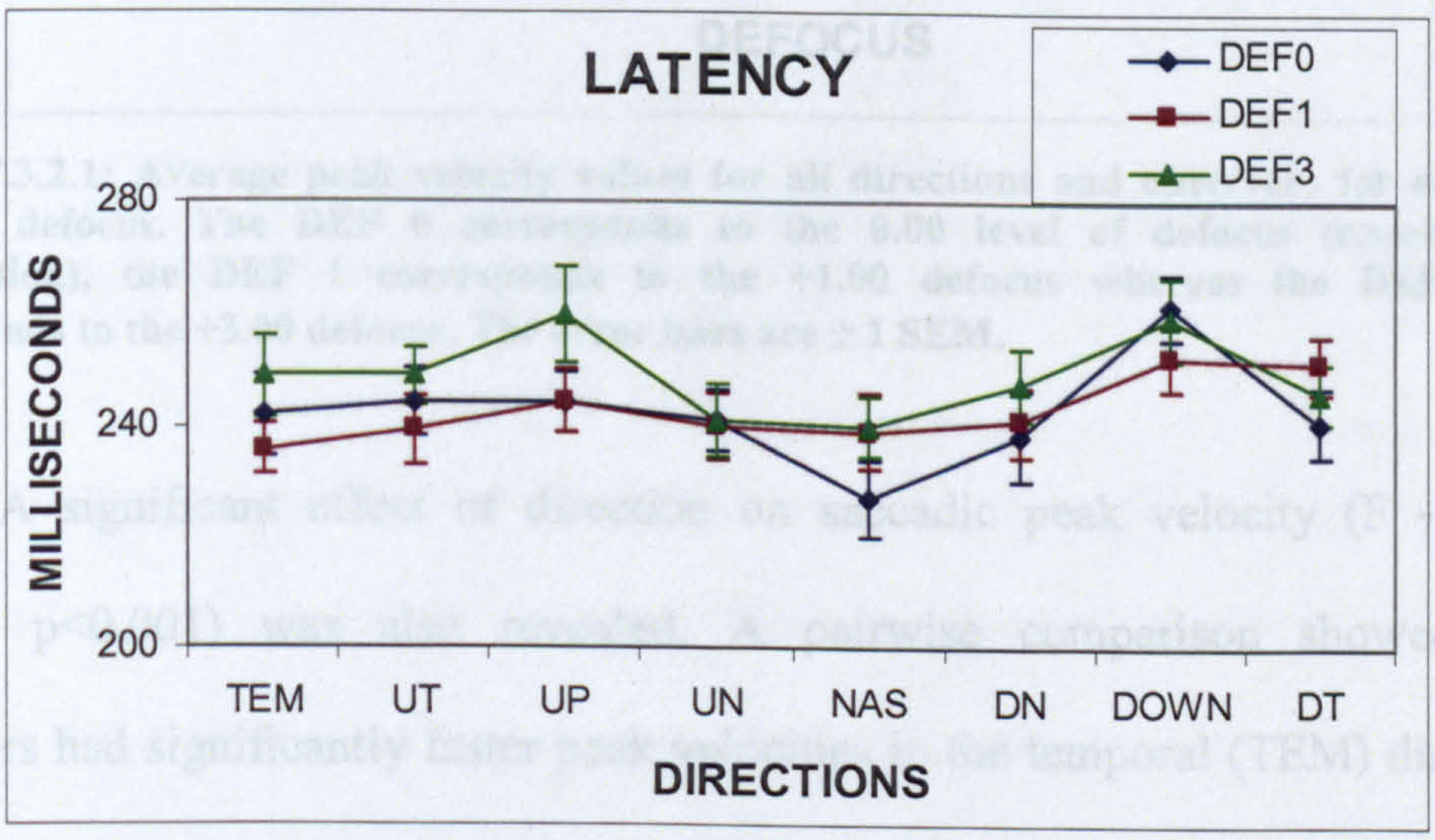


Figure 7.3.1.1: Average latency values of all observers for each direction separately and each level of defocus. The blue diamonds correspond to the 0.00 level of defocus (required prescription), the magenta square correspond to the +1.00 defocus whereas the green triangle correspond to the +3.00 defocus. The error bars show ±1SEM.

7.3.2 *Peak Velocity*

The analysis of variance revealed a significant effect of defocus ($F_{2,\ 38}$ = 8.21, p =0.001). Figure 7.3.2.1 shows the average peak velocity value in each level of defocus with all directions combined. A pairwise comparison revealed that peak velocities values for the +3.00DS condition were significantly slower than the 0.00DS (by approximately 25 deg/sec) and the +1.00DS (by an average 26 deg/sec) conditions. The 0.00DS and +1.00DS level of defocus were not significantly different.

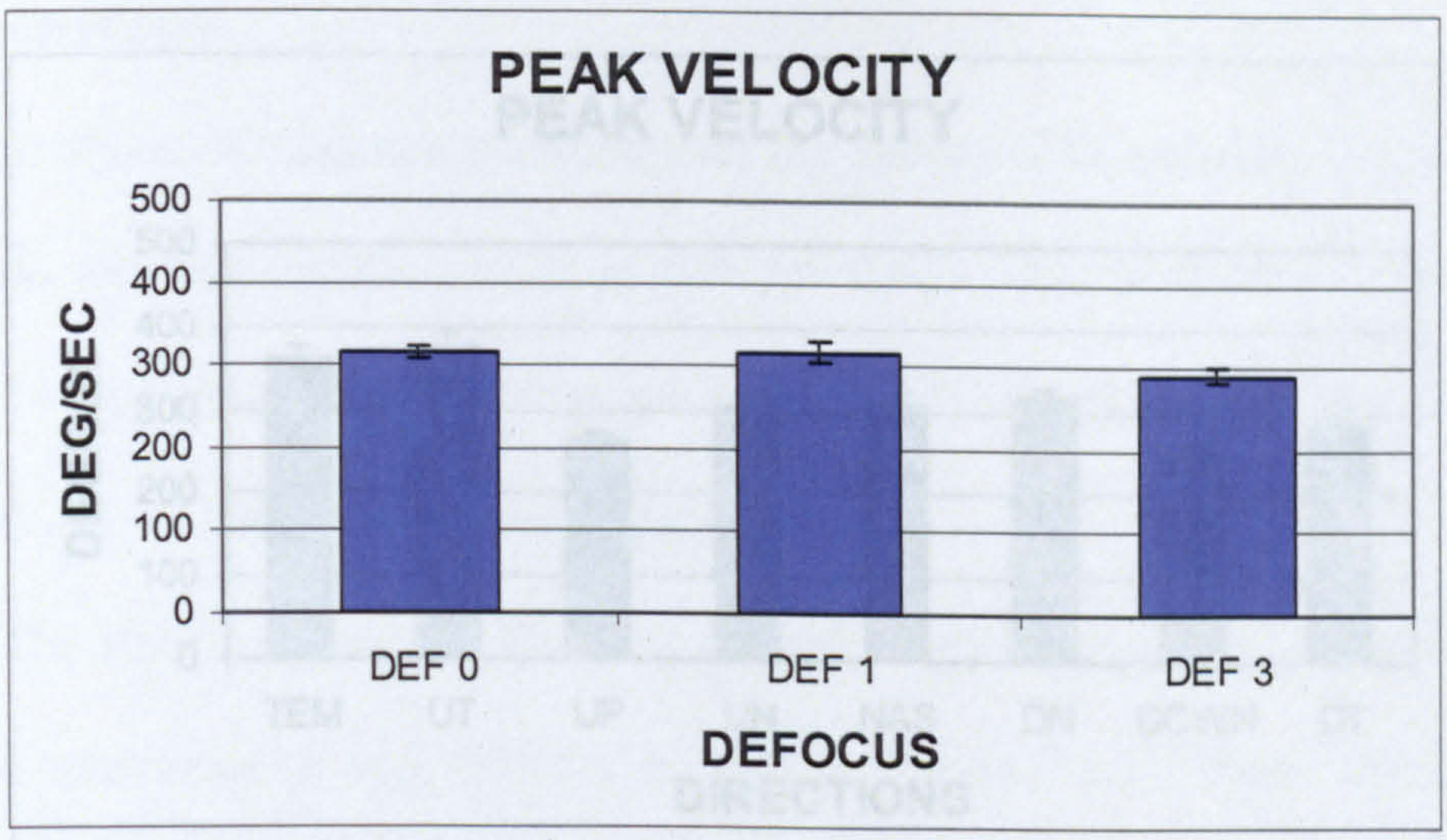


Figure 7.3.2.1: Average peak velocity values for all directions and observers for each level of defocus. The DEF 0 corresponds to the 0.00 level of defocus (required prescription), the DEF 1 corresponds to the +1.00 defocus whereas the DEF 3 corresponds to the +3.00 defocus. The error bars are ± 1 SEM.

A significant effect of direction on saccadic peak velocity ($F_{7, 133}$ = 13.885, p<0.001) was also revealed. A pairwise comparison showed that observers had significantly faster peak velocities in the temporal (TEM) direction compared to both vertical ones (UP, DOWN) and the down temporal (DT). The up temporal (UT) direction showed significantly faster peak velocities compared to the up (UP) (Figure 7.3.1.2). Similar relationships between these directions have been previously observed (section 6.3.2.2) when the effect of direction was investigated under different viewing distances. The same subjects were used in both experiments.

In addition, observers showed significantly higher peak velocities in the nasal (NAS) direction compared to the down (DOWN) direction by approximately 57 deg/sec. Other directions that indicated significantly lower peak velocities compared to the up temporal (UT) was the down (DOWN) and the down temporal (DT). Moreover, observers showed significantly lower peak velocities in the down direction compared to the down-nasal (DN) direction by an average 63 deg/sec.

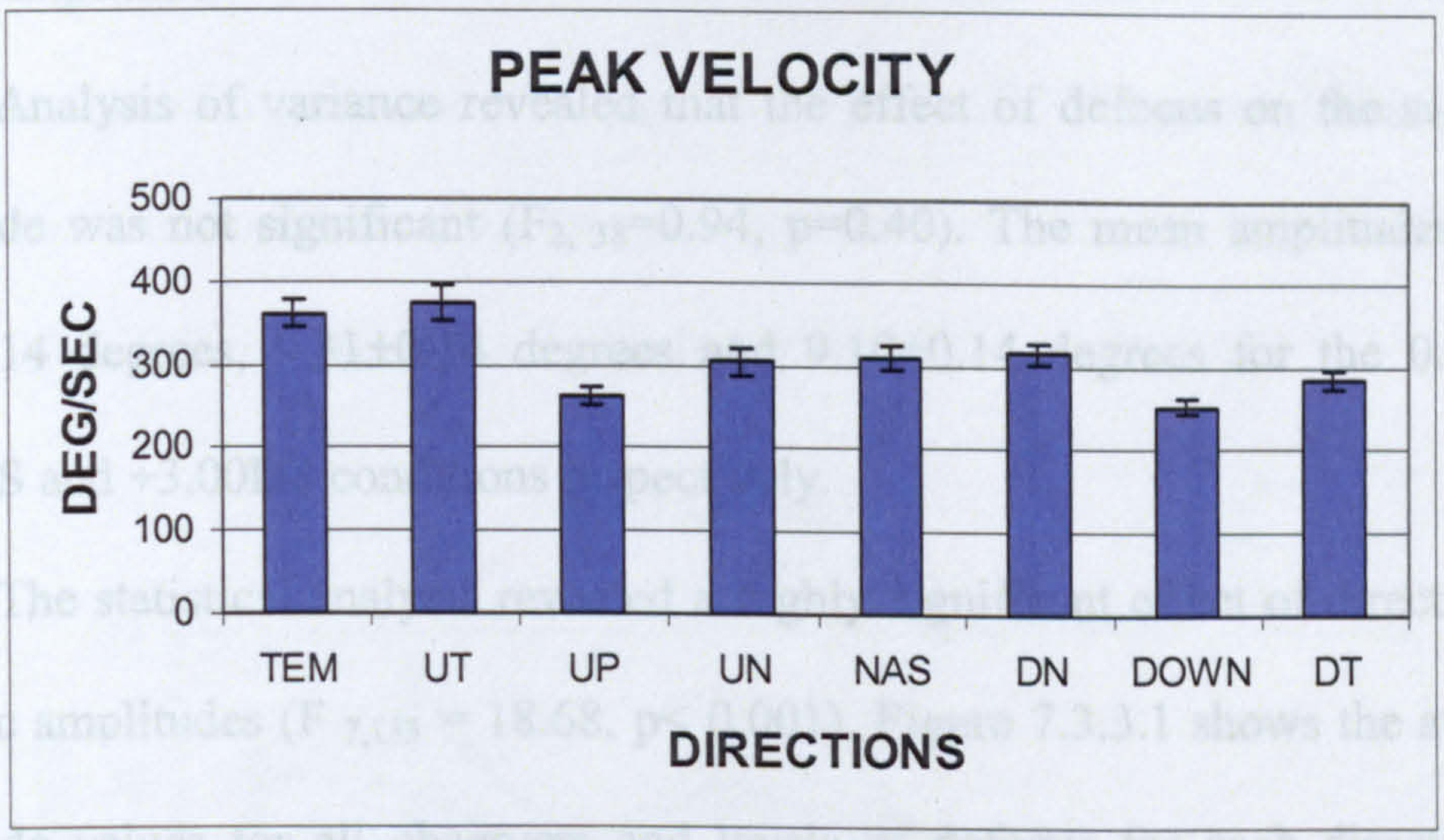


Figure 7.3.2.2: Average peak velocity values of all observers for each direction separately when all levels of defocus were combined. The error bars indicate the standard error of the mean.

The interaction effect between direction and defocus for peak velocity was not significant ($F_{14, 266}$ = 1.84, p=0.86). Therefore, the way observers performed under the different levels of defocus was similar for each direction. Figure 7.3.2.3 shows the average peak velocity for each direction and each level of defocus respectively.

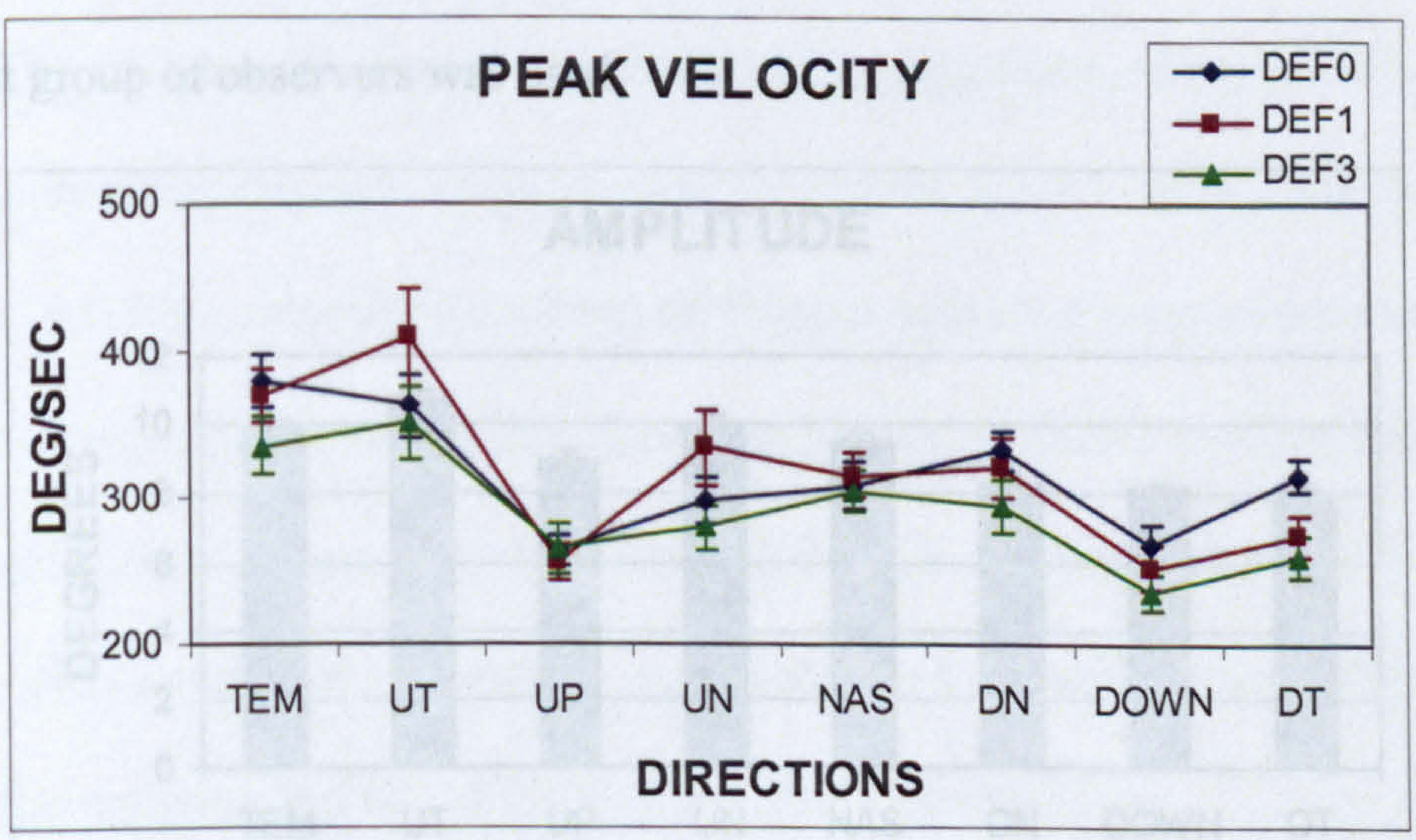


Figure 7.3.2.3: Average peak velocity values of all observers for each direction separately and each level of defocus. The blue diamonds correspond to the 0.00 level of defocus (required prescription), the magenta square correspond to the +1.00 defocus whereas the green triangle correspond to the +3.00 defocus. The error bars are ± 1 SEM.

7.3.3 *Amplitude*

Analysis of variance revealed that the effect of defocus on the saccadic amplitude was not significant ($F_{2,\,38}$=0.94, p=0.40). The mean amplitudes were 9.18±0.14 degrees, 9.31±0.14 degrees and 9.10±0.14 degrees for the 0.00DS, +1.00DS and +3.00DS conditions respectively.

The statistical analysis revealed a highly significant effect of direction on saccadic amplitudes ($F_{7,133}$ = 18.68, p< 0.001). Figure 7.3.3.1 shows the average amplitude values for all observers and levels of defocus for each direction. A pairwise comparison revealed that observers had significantly larger saccadic amplitudes in the temporal (TEM), nasal (NAS), up-temporal (UT) and up-nasal (UN) directions compared to the those with a downward component (DOWN, DT, DN).

In addition, a visual inspection of Figure 7.3.3.1 reveals that observers undershoot (less than 10 degrees) in all directions with a downward component (DOWN, DT, DN). This observation has also been made in Chapter four where a different group of observers was used.

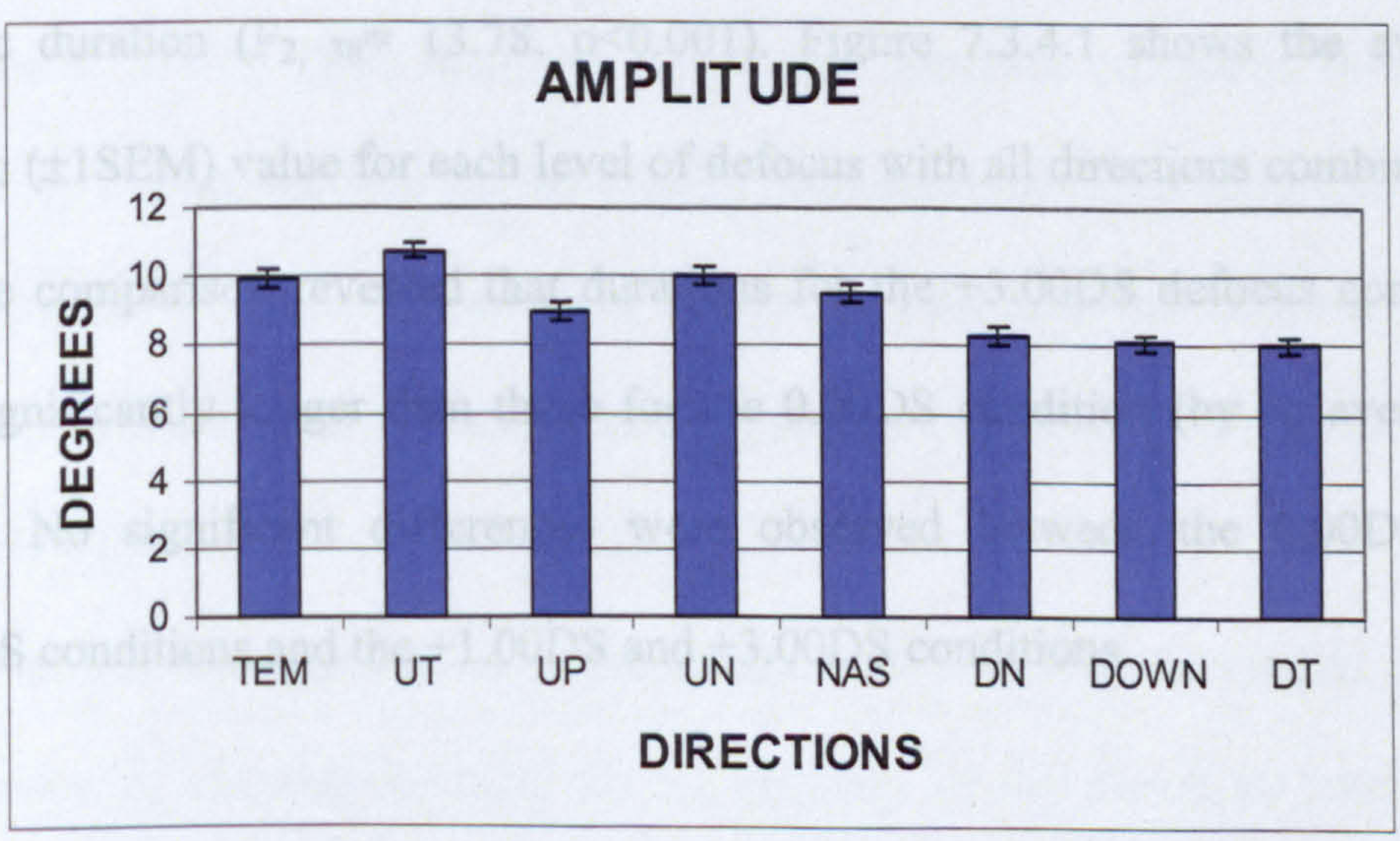


Figure 7.3.3.1: average amplitude values of all observers for each direction separately when all levels of defocus were combined. The error bars indicate the standard error of the mean.

The interaction effect between defocus and directions for saccadic amplitude was not significant ($F_{14, 266} = 2.13$, $p = 0.06$). This result indicates that the variation in amplitude with direction was similar for each level of defocus (Figure 7.3.3.2). Error bars are ± 1 standard error of the mean.

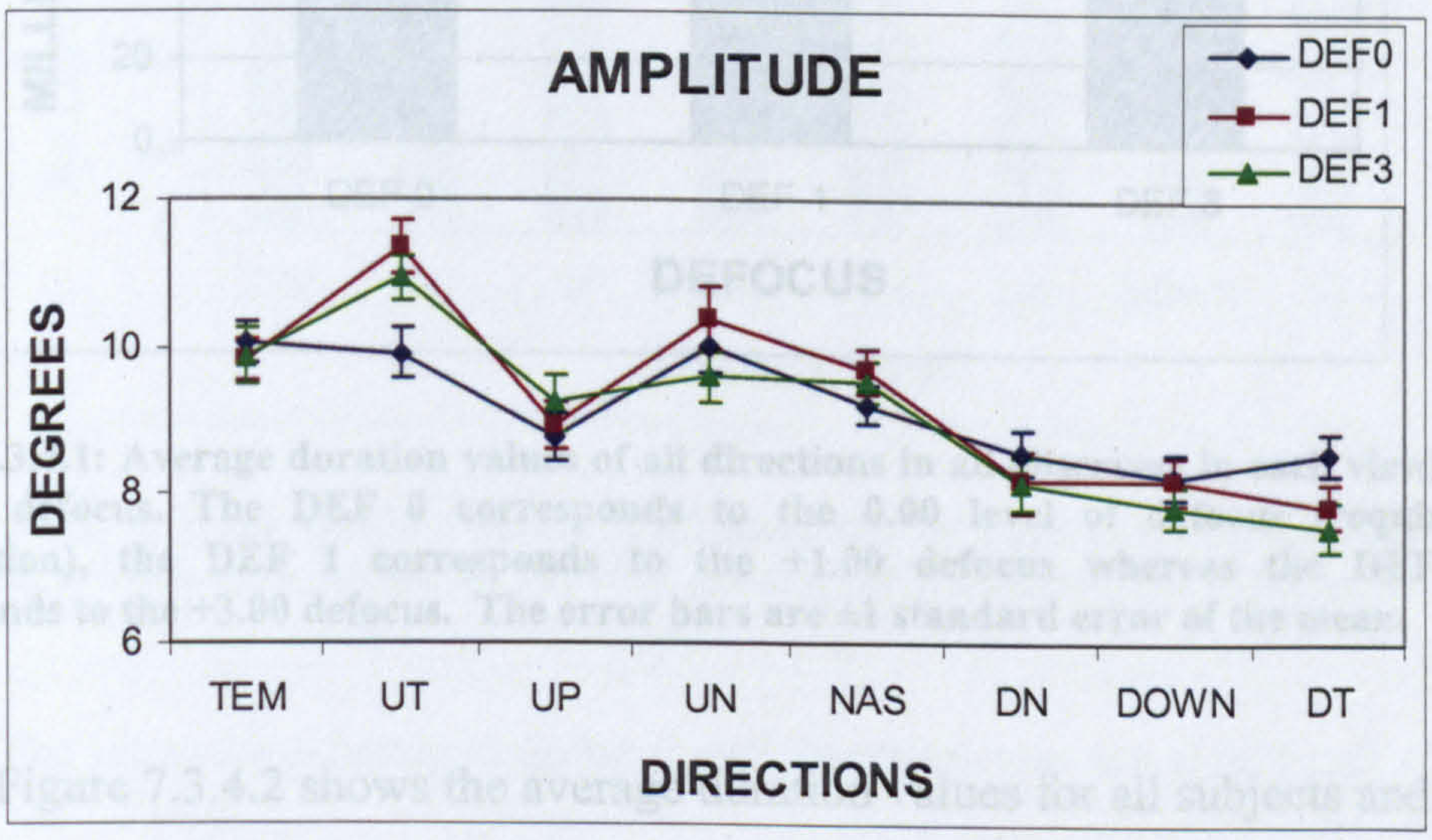


Figure 7.3.3.2: Average amplitudes (all observers) for each direction and each level of defocus. The blue diamonds correspond to the 0.00 level of defocus (required prescription), the magenta square correspond to the +1.00 defocus whereas the green triangle correspond to the +3.00 defocus. The error bars are ±1SEM.

7.3.4 *Duration*

The analysis of variance revealed a highly significant effect of defocus on saccadic duration ($F_{2, 38} = 13.78$, $p<0.001$). Figure 7.3.4.1 shows the average duration (±1SEM) value for each level of defocus with all directions combined. A pairwise comparison revealed that durations for the +3.00DS defocus condition were significantly longer than those for the 0.00DS condition (by an average 8 msecs). No significant differences were observed between the 0.00DS and +1.00DS conditions and the +1.00DS and +3.00DS conditions.

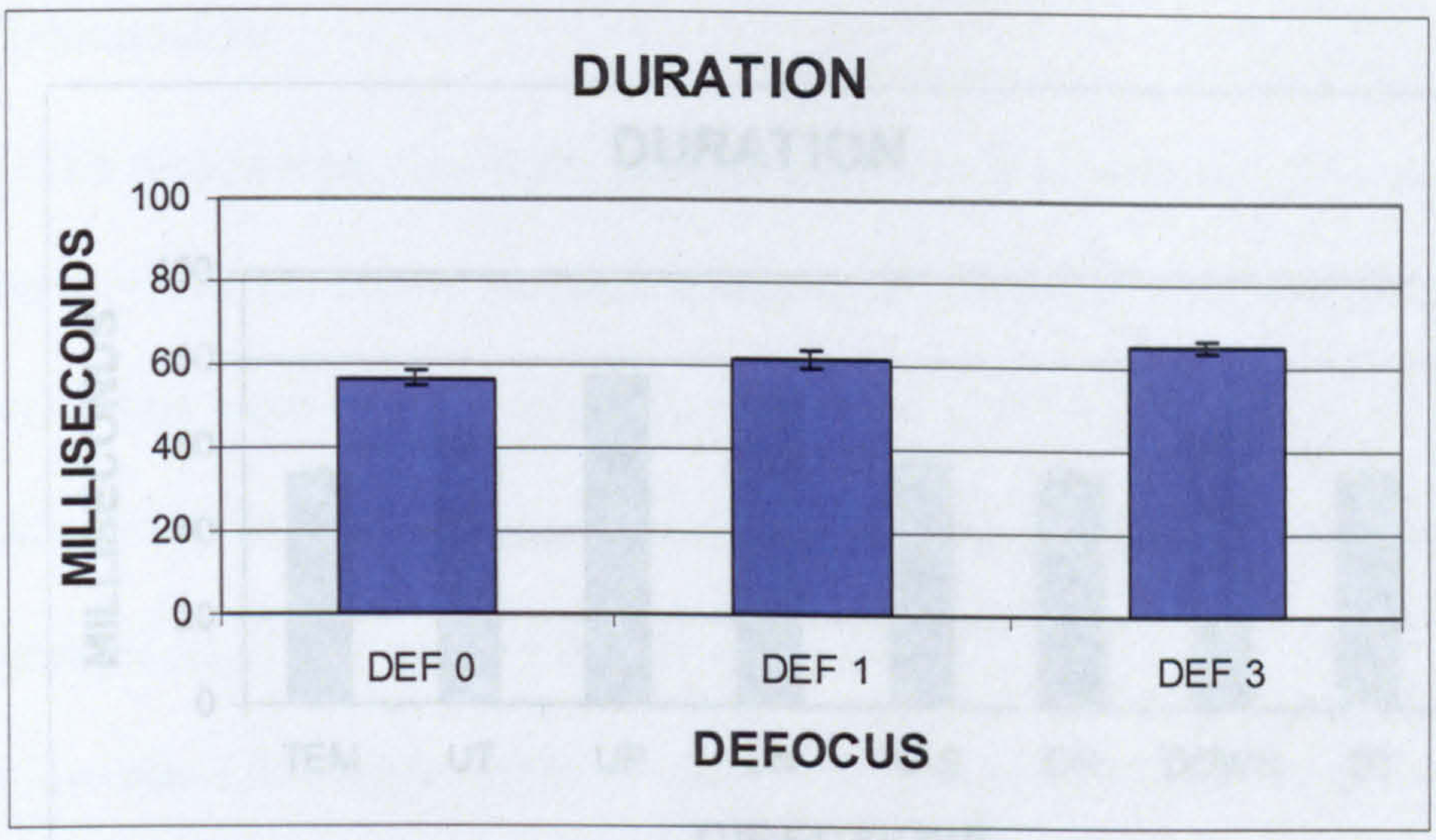


Figure 7.3.4.1: Average duration values of all directions in all observers in each viewing level of defocus. The DEF 0 corresponds to the 0.00 level of defocus (required prescription), the DEF 1 corresponds to the +1.00 defocus whereas the DEF 3 corresponds to the +3.00 defocus. The error bars are ±1 standard error of the mean.

Figure 7.3.4.2 shows the average duration values for all subjects and levels of defocus in each direction. Analysis of variance revealed a significant effect of direction on saccadic duration ($F_{7,133} = 24.70$, $p < 0.001$). A pairwise comparison showed that saccades were significantly longer in durations for both the up (UP) and up-nasal (UN) directions compared to the horizontal directions (TEM, NAS), to the oblique directions with a downward component (DT, DN). Moreover, observers in the up (UP) direction had longer duration compared to the up temporal (UT) one. Whereas the latter (UT) had longer durations compared to the down nasal (DN) direction. In addition, observers in the temporal direction (TEM) showed significantly shorter durations compared to the nasal (NAS) and the up temporal (UT).

Similar relationships have previously been observed in section 6.3.4.2 (comparison of viewing distance) for the majority of the directions mentioned. This finding indicates a consistent effect of direction on saccadic duration despite the different conditions and recording sessions.

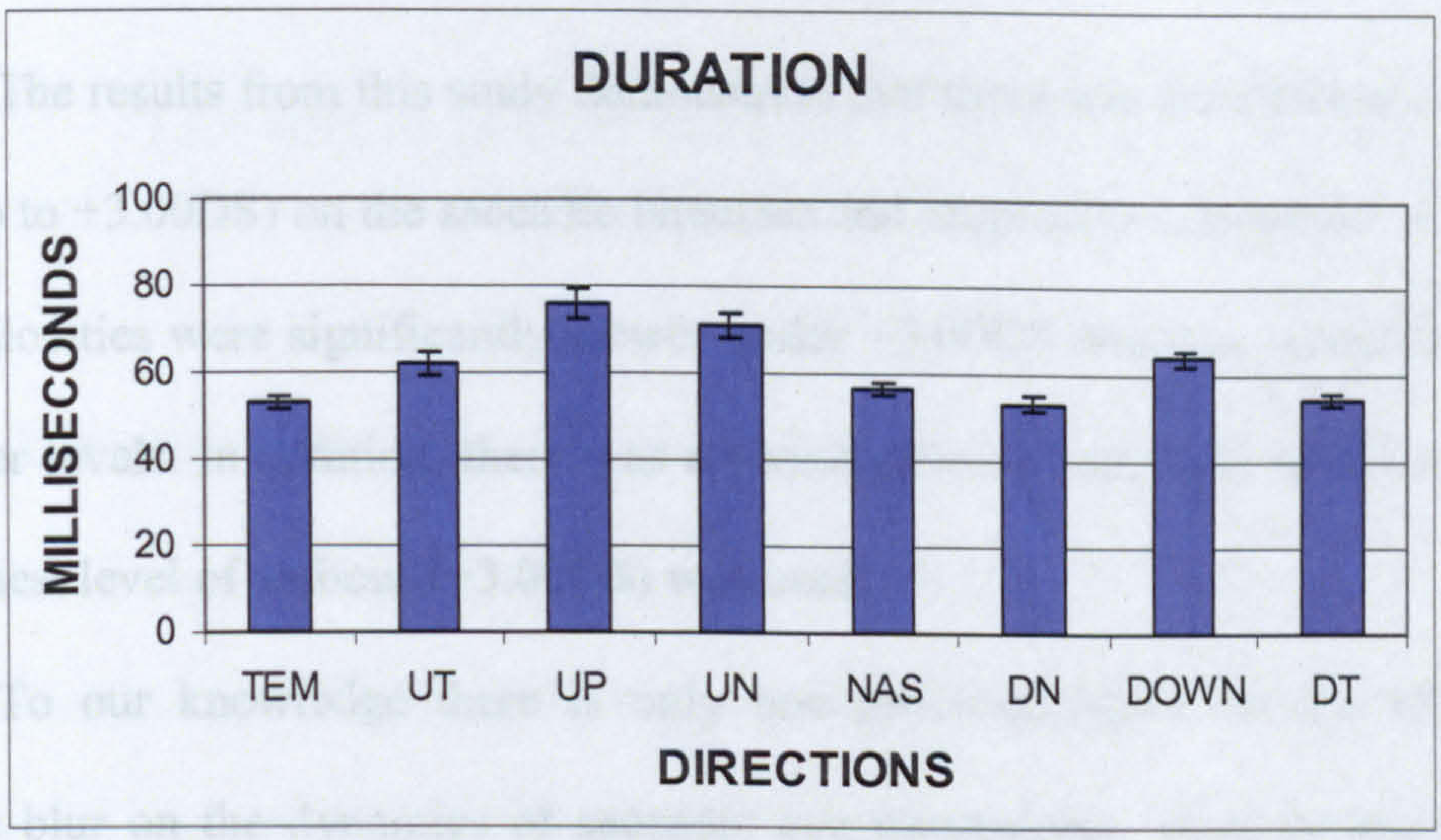


Figure 7.3.4.2: Average duration values of all observers for each direction separately when all levels of defocus were combined. The bars indicate the standard error of the mean.

The interaction between defocus and direction was not significant ($F_{14, 266} = 1.35$, $p = 0.18$). This result indicates that the effect of direction on duration was not significantly different between the three levels of defocus. This can be seen in Figure 7.3.4.3. The error bars indicate the standard error of the mean.

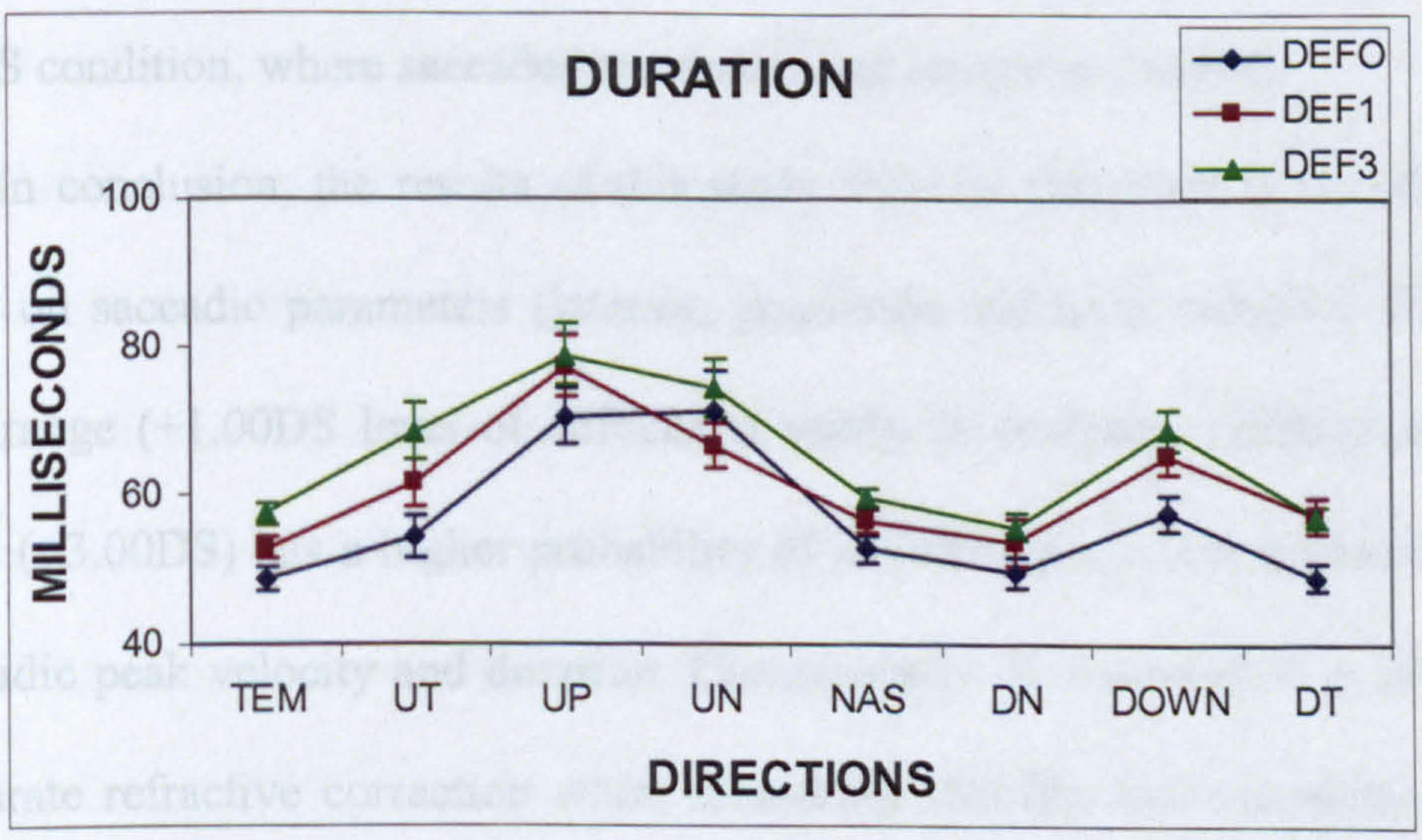


Figure 7.3.4.3: Average duration values of all observers for each direction separately and each level of defocus. The blue diamonds correspond to the 0.00 level of defocus (required prescription), the magenta square correspond to the +1.00DS defocus whereas the green triangle correspond to the +3.00DS defocus. The error bars are ±1SEM.

7.4 Discussion

The results from this study demonstrate that there was no effect of dioptric blur (up to +3.00DS) on the saccadic latencies and amplitudes. However, saccadic peak velocities were significantly slower under +3.00DS defocus, compared with the other levels. In addition, there was a prolongation of saccadic duration when the highest level of defocus (+3.00DS) was used.

To our knowledge there is only one previous report on the effect of dioptric blur on the dynamics of saccadic eye movements. Ukwade and Bedell (1993) used an infrared technique and investigated the stability of oculomotor fixation as a function of target contrast and blur. From their study on fixation stability and vergence, they concluded that eye movements, should not be affected by residual refractive errors as long as the level of defocus is less than +1.00DS. In our study, we looked more closely at specific saccadic parameters; however, our results also show no effect of +1.00DS defocus. An effect is seen for the +3.00DS condition, where saccades are slower and longer in duration.

In conclusion, the results of this study indicate that there is no effect of defocus on saccadic parameters (latency, amplitude and peak velocity) within a certain range (+1.00DS level of defocus is used). In contrast, a higher level of defocus (+3.00DS) has a higher probability of interfering with the measurements of saccadic peak velocity and duration. Consequently, it is advisable to establish an accurate refractive correction when measuring saccadic eye movements in a clinical environment. An accurate refractive correction is necessary to ensure that any change from normal values is due to pathology rather than the recording conditions.

CHAPTER 8:

The effect of cataract simulation on saccadic eye movements.

8.1 Introduction

The purpose of this study was to investigate the effect of simulated impaired vision (i.e. cataracts) on the dynamics of saccadic eye movements. Cataract was chosen, as it is the most common cause of visual impairment in developed countries.

To our knowledge, there is only one study that has investigated the effect of cataractous vision on saccadic eye movements. Bowers and Reid (1997) investigated the effect of simulated cataracts on the reading eye movements of young normal observers. Compared to normal vision, they found that both page navigation duration and the duration of fixation pauses were longer with the cataract condition.

Cataract principally decreases visual function by increased intra-ocular light scattered decreasing the contrast of the retinal image. The effects of cataract on the saccadic eye movement parameters are therefore likely to mirror the effects of contrast reduction (Elliott, 1993). The literature indicates that saccadic latency (reaction time) increases with decreased target contrast in the horizontal direction (Wheeless, *et al.* 1967; Ludwig, *et al.* 2004). However, there appears to be no indication of how changes in contrast level affect saccadic peak velocity, amplitude or duration in different directions of gaze.

Several studies have investigated the effect of target contrast changes on involuntary eye movements occurring during fixation (Carifa and Hebbard, 1967), on dynamic visual acuity and eye movements (Brown, 1972) and on smooth pursuit eye movements (Haegerstrom and Brown, 1979). Carifa and Hebbard (1967) reported that the precision of monocular fixation on a very thin illuminated ring target worsens only when the target contrast falls below 6%. It has been proposed that this effect was due to the reduction in target visibility at these very low contrasts (Ukwade and Bedell, 1993). Indeed, Ukwade and Bedell (1993) reported no significant effect on fixation stability for target contrasts between 7% and 84%. Brown (1972), using a photoelectric device to record eye movements, reported that the velocity of smooth pursuit eye movements decreased as the level of contrast was reduced from 70% to 23%. He also reported that the latencies of the first and second saccade during the tracking of a target increased with decreasing contrast levels. Haegerstrom and Brown (1979) determined the contrast detection thresholds for four target velocities (5, 15, 25 and 40°/sec). They found that the velocity of smooth pursuit eye movements increased with increases in target contrast up to approximately 0.3 log units above each subject's designated detection threshold. Further increases in contrast had little effect. In addition, they reported a steady increase in saccadic latency as target contrast is decreased relative to the detection threshold. The results of these studies indicate that changes in contrast have an effect on saccadic and smooth pursuit eye movements.

Although it is well accepted that cataracts affect the perception of contrast and a variety of everyday tasks, there are no reports on how (or if) this visual impairment affects the dynamics of saccadic eye movements. Therefore it is appropriate to establish if cataractous vision has any effect on saccadic eye movements in order to explore thoroughly the robustness of saccadic eye movement measurements as a clinical tool.

8.2 Methods

8.2.1 Eye movement apparatus / Stimulus / Recording system

The monitoring apparatus (IRIS 6500) and stimulus were used in this experiment as described previously in Chapter four. The recording system consisted of a laptop running LABVIEW 6.1 as previously described (Chapter three).

8.2.2 Observers

Twenty visually normal observers were recruited from the staff and student population of University of Bradford in order to participate in this study. Their ages ranged from 20 to 39 years (median 25.5 years). Thirteen of the subjects were female. Subjects participating in the study had no systemic disease and were not under medication that is known to affect saccadic eye movements.

Prior to the collection of eye movement data, all subjects underwent a series of preliminary optometric tests (LogMAR visual acuity, cover test, motility, stereopsis and contrast sensitivity) to establish that their binocular vision was normal. All subjects demonstrated a TNO stereoscopic acuity better than 60 secarc. Visual acuity in all observers was at least 0.0 LogMAR. An optical correction was used if necessary in the form of the subjects' own contact lenses or full aperture trial case lenses. The use of the Vistech cataract simulation goggles reduced visual acuities by nearly four lines (0.4±0.15 LogMAR). This result comes in agreement to Patel et al (2001) who used the same type of cataract simulation. The contrast sensitivity score using a Pelli-Robinson chart at 100 cm with letter-by-letter scoring without the cataract simulation was 1.85±0.05 log units and with the simulation was 1.00±0.05 log units. This reduction of contrast sensitivity (0.85 log units) is similar to the level induced by a dense cataract (Elliott, *et al.* 1996; Anand *et al.* 2003). Similar results have been reported in other studies that have used the same Vistech goggles (Elliott, *et al.* 1996; Patel, *et al.* 2001; Anand *et al.* 2003).

8.2.3 Experimental procedure / Data processing

The experimental procedure was the same as that described in Chapter four. Briefly, monocular recordings of 10-degree saccadic eye movements in eight different directions of gaze (TEM, NAS, UP, DOWN, UN, DT, UT, DN) were collected. All measurements were made with and without the cataract simulation. The data processing in this study was also identical to the one described in Chapter three.

8.2.4 Cataract simulation

Vistech light scattering goggles (Vistech Consultants Inc. Dayton, OH) were used in order to simulate the cataractous vision in this study. To simulate a dense cataract, two visors were fitted simultaneously on the sensors of the eye tracker or attached to a full aperture lens holder. This latter location was used if lenses were required to correct the subjects' refractive error.

The selection of this type of simulation was due to the fact that these goggles have been found to scatter light with a similar distribution as the one observed in cataract patients. That is to say, they reduce the retinal contrast of the target due to forward light scatter and the retinal illumination due to back scatter (Elliott, *et al.* 1996). This type of simulation has been used in other published studies (Elliott, *et al.* 1996; Patel, *et al.* 2001; Anand *et al.* 2003).

8.3 Results

Data were collected for each saccadic parameter (latency, peak velocity, amplitude and duration) in all eight directions with a double cataract simulation. For each subject, individual values were obtained and the average and standard deviation from four repeated measurements was calculated. A repeated measures ANOVA with several independent variables was applied for each saccadic parameter separately. The within factors were the viewing conditions (normal versus cataractous vision) and directions.

8.3.1 Latency

Analysis of variance revealed a highly significant effect of cataract simulation on saccadic latency ($F_{1, 19} = 29.40$, $p < 0.001$). Observers' latencies with the cataract simulation were longer by an average of 18 msecs compared to the ones obtained with their normal vision (Figure 8.3.1.1).

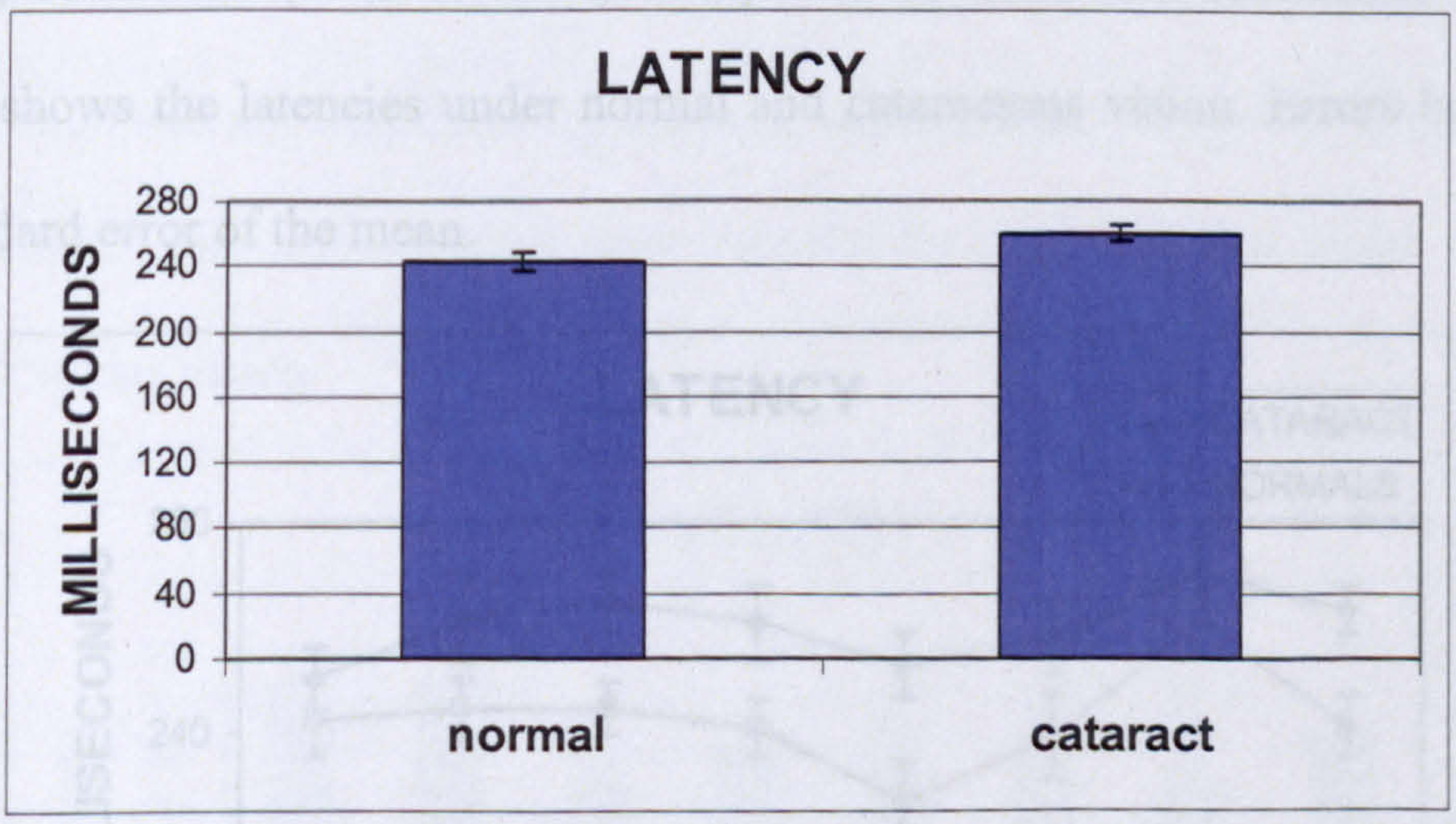


Figure 8.3.1.1: Average latency values for all directions in all observers without (normal) and with the cataract simulation. Error bars are ±1 standard error of the mean.

Statistical analysis also showed a significant effect of direction on saccadic latency ($F_{7, 133} = 4.02$, $p = 0.01$). Pairwise comparisons between directions indicated a significant difference (p= 0.01) between the mean latency of the down (DOWN) direction compared to the nasal (NAS) direction and a borderline significant difference (p=0.05) compared to the temporal (TEM) direction. Observers needed longer latencies in the downward direction by an average of 20 msecs to the temporal (TEM) direction and by approximately 25 msecs when compared to the nasal (NAS) direction. A similar result was also observed previously in section 6.3.1.2 (effect of viewing distance), where observers had longer latencies in the down direction by an average 25 msecs than the nasal one and in section 7.3.1.3 (effect of dioptric blur), where observers had longer latencies when looking down by approximately 20 msecs than the nasal direction.

The interaction effect between the effect of cataract simulation and direction was not significant ($F_{7,\,133} = 1.01$, p=0.42). This result indicates that the effect of direction on latency was not significantly different between the two viewing conditions (cataract and normal). For all observers combined, Figure 8.3.1.2 shows the latencies under normal and cataractous vision. Errors bars are ±1 standard error of the mean.

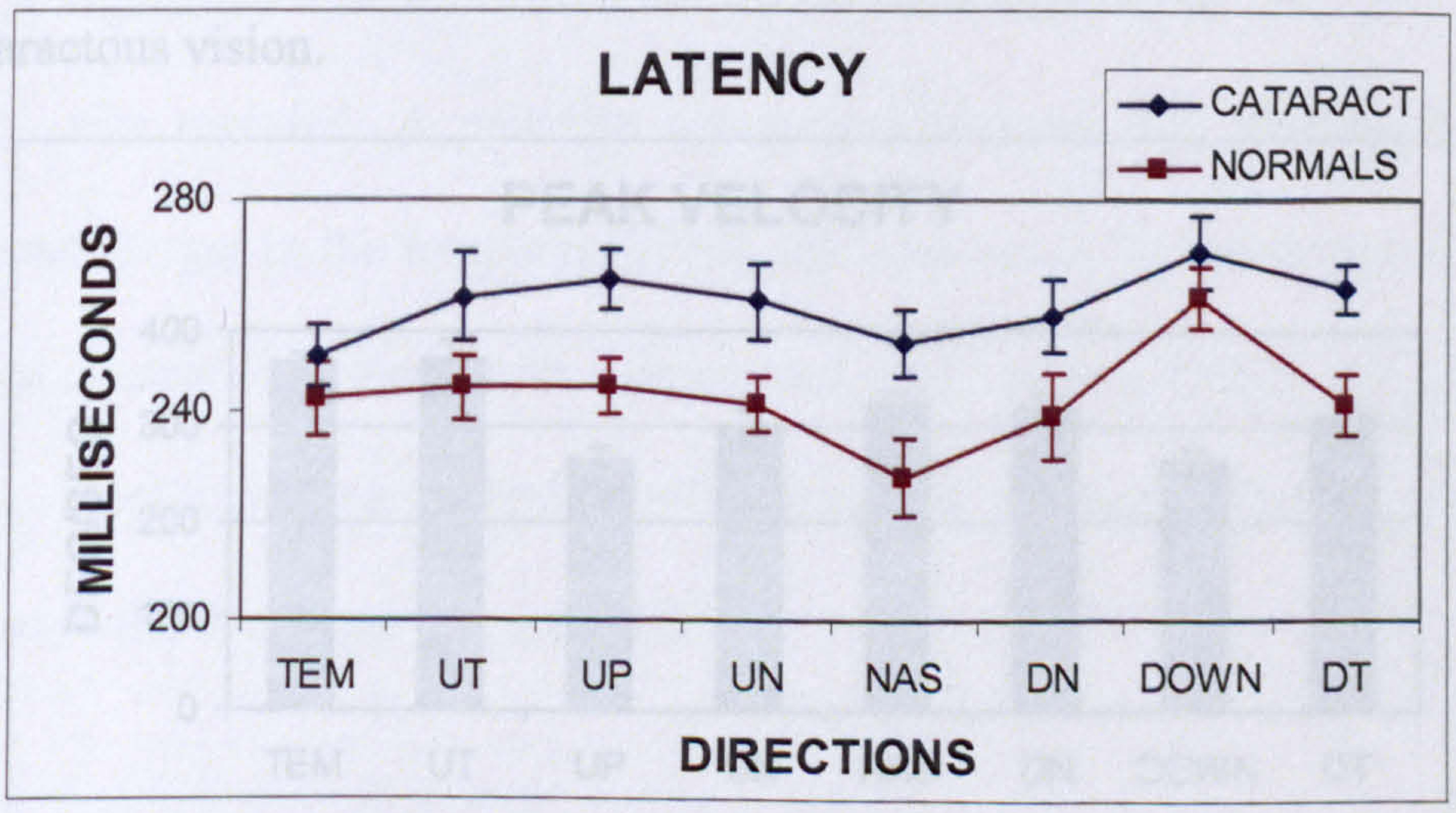


Figure 8.3.1.2: Average latency values of 20 observers for each direction and each viewing condition. The blue diamonds correspond to the latencies obtained with cataractous vision; the magenta squares correspond to the normal vision. Error bars show the standard error of the mean.

8.3.2 Peak Velocity

Analysis of variance revealed no effect of cataractous vision on saccadic peak velocity ($F_{1, 19} = 0.05$, p=0.83). The average peak velocities were 316±8 deg/sec and 315±7 deg/sec under normal and cataract conditions respectively.

A highly significant effect of direction on saccadic peak velocity was revealed ($F_{7, 133} = 11.57$, $p < 0.001$). Pairwise comparisons showed that vertical saccades (UP and DOWN) had significantly slower peak velocities when compared to both the temporal (TEM) and up-temporal (UT) ones. In addition, downward saccades (DOWN) were significantly slower than those in the nasal (NAS) direction and down-nasal (DN) direction (Figure 8.3.2.1). Similar results have been previously reported (sections 6.3.2.2 / 7.3.2.2) indicating stability in our peak velocity measurements under different conditions and on different occasions.

The interaction between the viewing conditions (normal versus cataract) and direction was not significant for the peak velocity data ($F_{7, 133} = 1.18$, p=0.32). Figure 8.3.2.2 shows the average peak velocity for each direction under normal and cataractous vision.

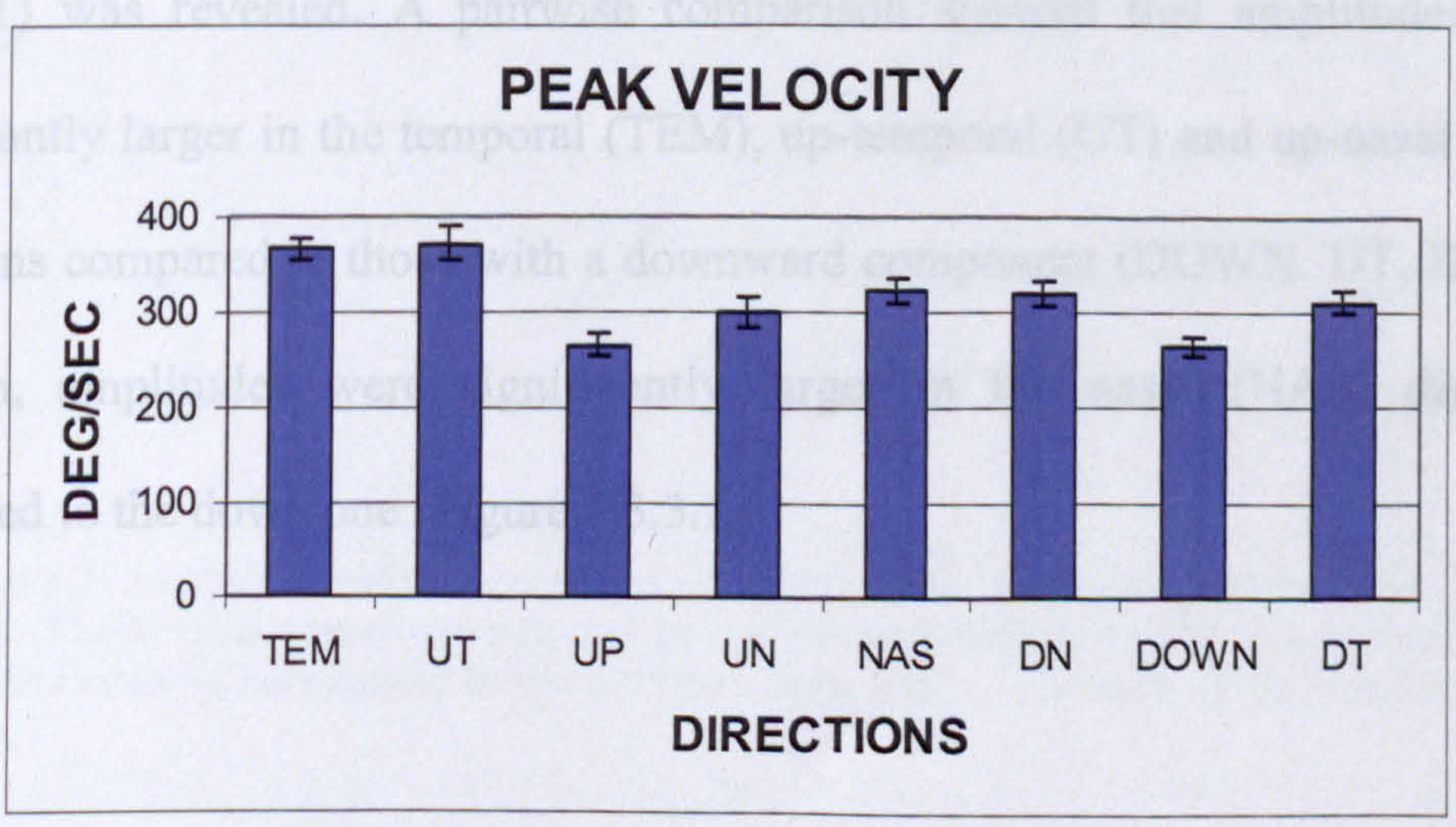


Figure 8.3.2.1: Average peak velocity values of all observers for each direction separately when the effect of viewing conditions was combined. The bars indicate the standard error of the mean.

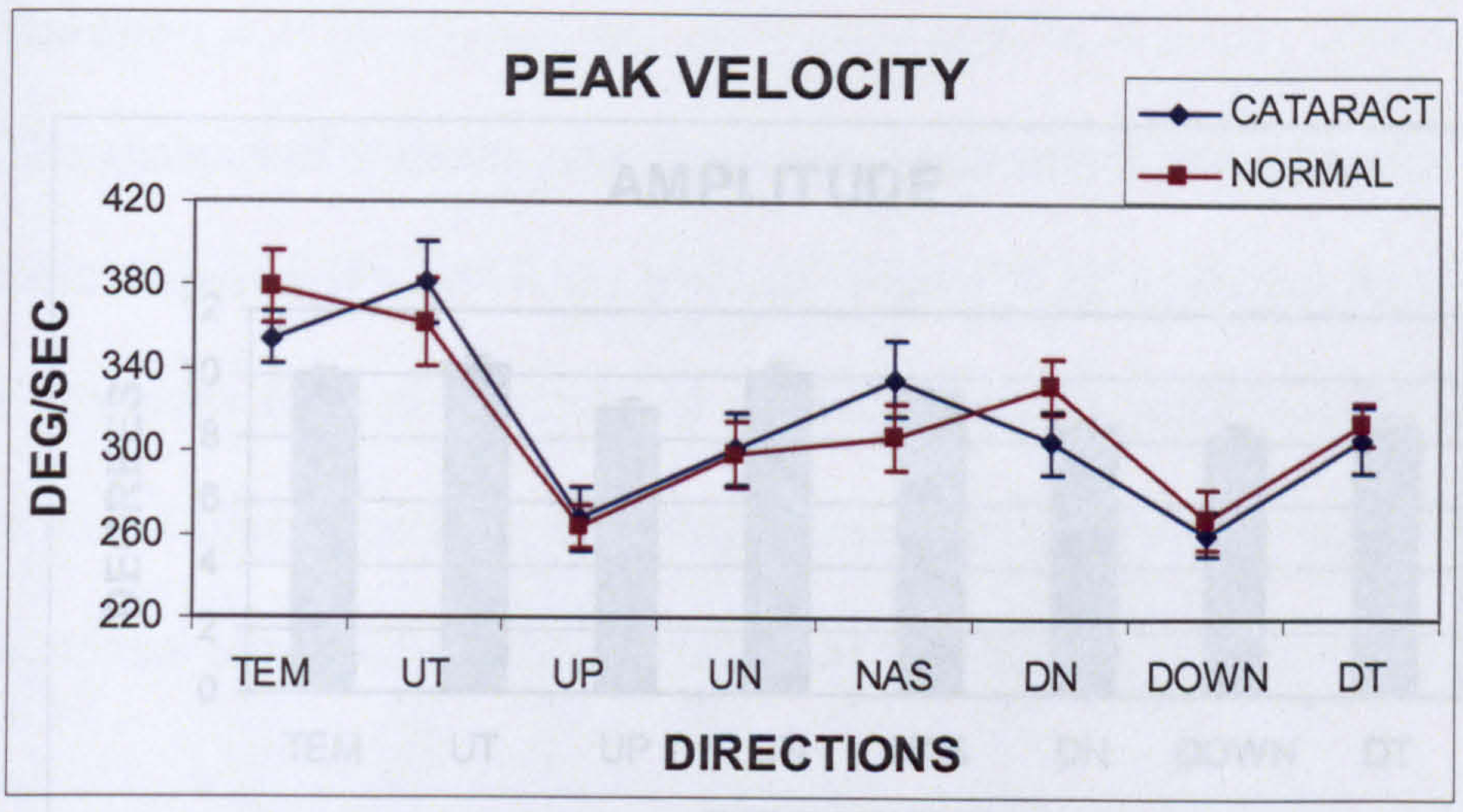


Figure 8.3.2.2: Average peak velocity values of 20 observers for each direction separately and each viewing condition. The blue diamonds correspond to the latencies obtained with cataractous vision; the magenta squares correspond to the normal vision. Error bars indicate standard error of the mean.

8.3.3 Amplitude

Analysis of variance indicated that there was no effect of the cataract simulation on saccadic amplitude ($F_{1,19}$=1.10, p=0.31). Average saccadic amplitudes were 9.18±0.14degrees and 9.34±0.09 degrees for the normal and cataract conditions respectively.

A significant effect of direction on saccadic amplitudes ($F_{7, 133}$ = 12.73, p<0.001) was revealed. A pairwise comparison showed that amplitudes were significantly larger in the temporal (TEM), up-temporal (UT) and up-nasal (UN) directions compared to those with a downward component (DOWN. DT, DN). In addition, amplitudes were significantly larger in the nasal (NAS) direction compared to the down one (Figure 8.3.3.1).

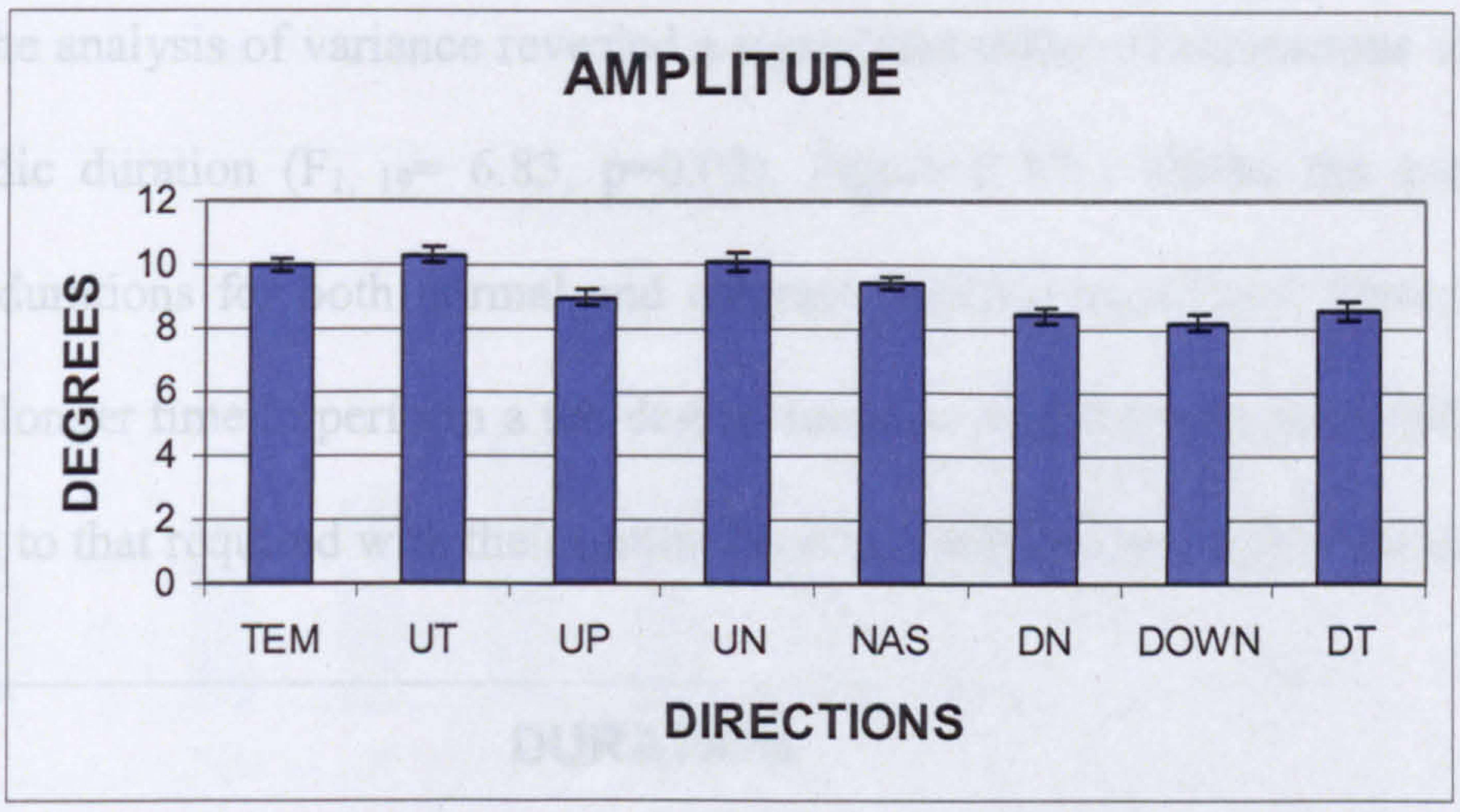


Figure 8.3.3.1: Average amplitude values from 20 observers for each direction. The error bars are ± 1 standard error of the mean.

The interaction between direction and viewing condition was not significant ($F_{7,133} = 0.88$, p=0.51). Therefore, the effect of direction on amplitude was similar for both viewing conditions.

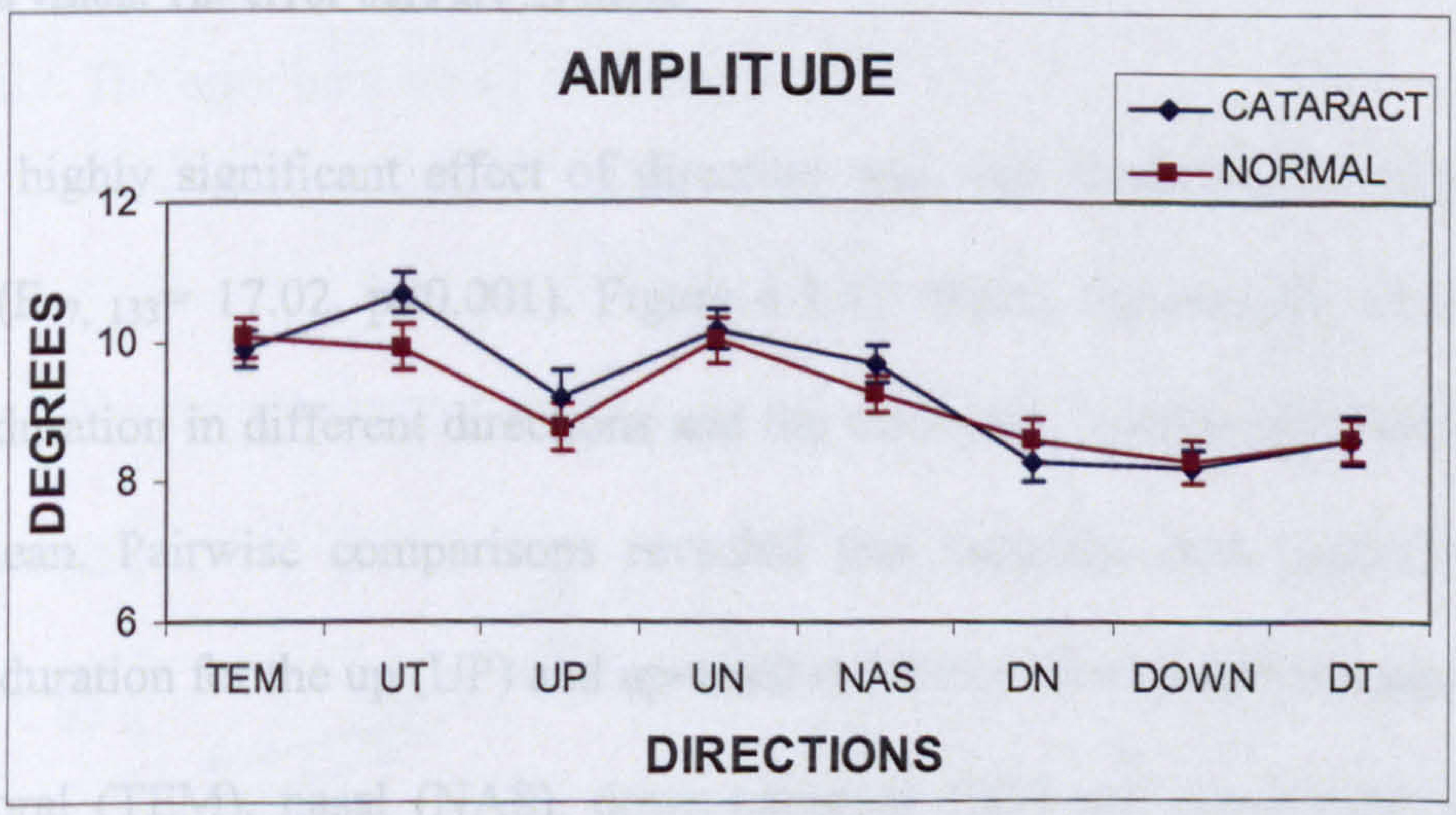


Figure 8.4.3.2: Average amplitude values of 20 observers for each direction and each viewing condition. The blue diamonds correspond to the latencies obtained with cataractous vision; the magenta squares correspond to the normal vision. Error bars show the standard error of the mean.

8.3.4 Duration

The analysis of variance revealed a significant effect of cataractous vision on saccadic duration ($F_{1,\ 19}$= 6.83, p=0.02). Figure 8.3.4.1 shows the average saccadic durations for both normal and cataract viewing conditions. Observers' needed a longer time to perform a ten-degree saccade with the cataract simulation compared to that required with their optimal correction by an average of 4 msecs.

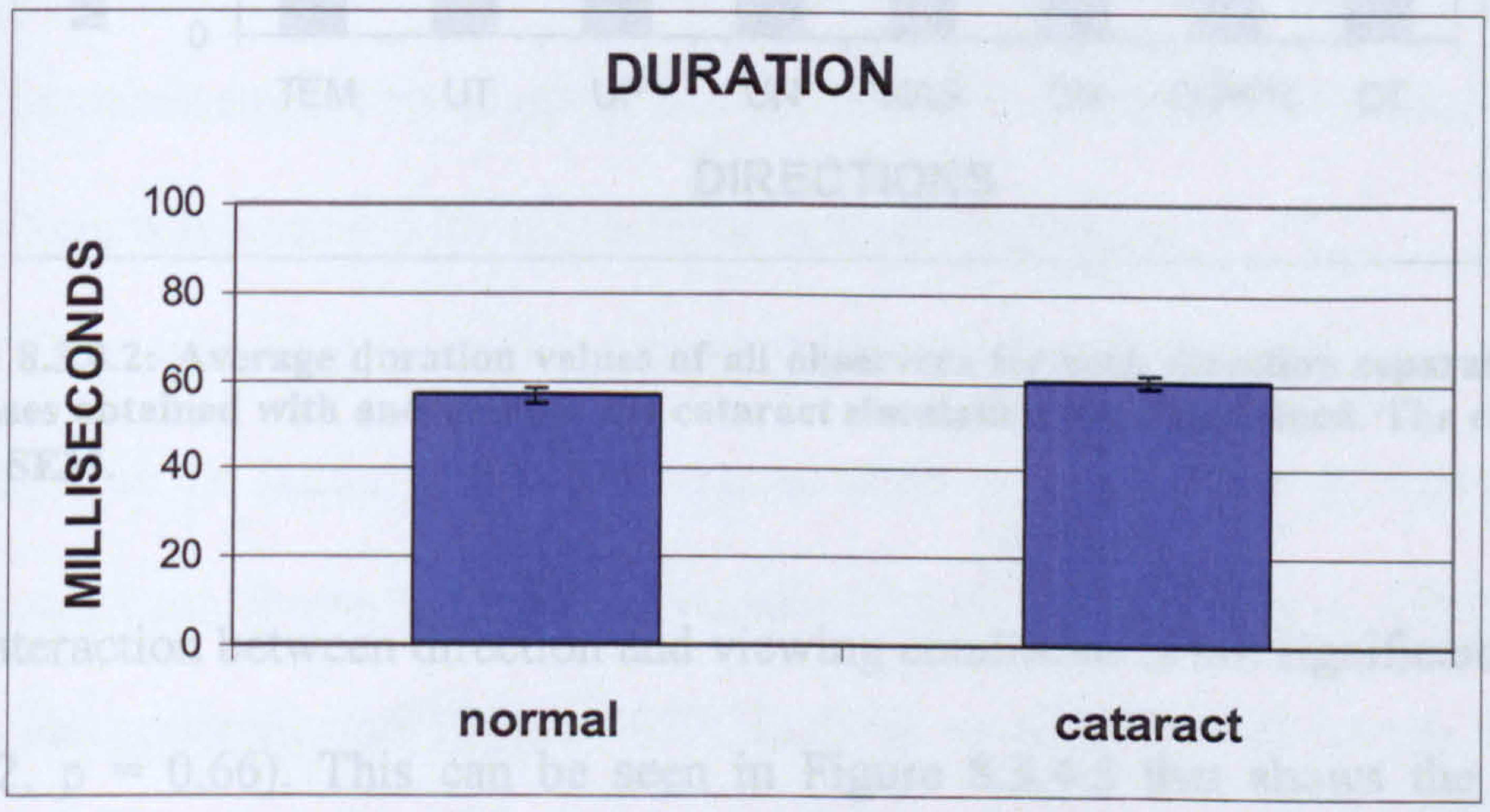


Figure 8.3.4.1: Average duration values for all directions in all observers under normal and cataractous vision. The error bars are ±1 SEM.

A highly significant effect of direction was also identified for saccadic duration ($F_{7,\ 133}$= 17.02, p<0.001). Figure 8.3.4.2 shows the average values of saccadic duration in different directions and the error bars indicate standard error of the mean. Pairwise comparisons revealed that saccades were significantly longer in duration for the up (UP) and up-nasal (UN) directions when compared to the temporal (TEM), nasal (NAS), down-temporal (DT) and down-nasal (DN) directions. In addition, saccades in the up (UP) direction were significantly longer in duration compared to the down (DOWN) and up-temporal (UT) directions. Similar effects of direction on duration have been identified in previous chapters

(6.3.4.2 and 7.3.4.2) indicating that measurements of saccadic duration are repeatable even under different conditions and on separate occasions.

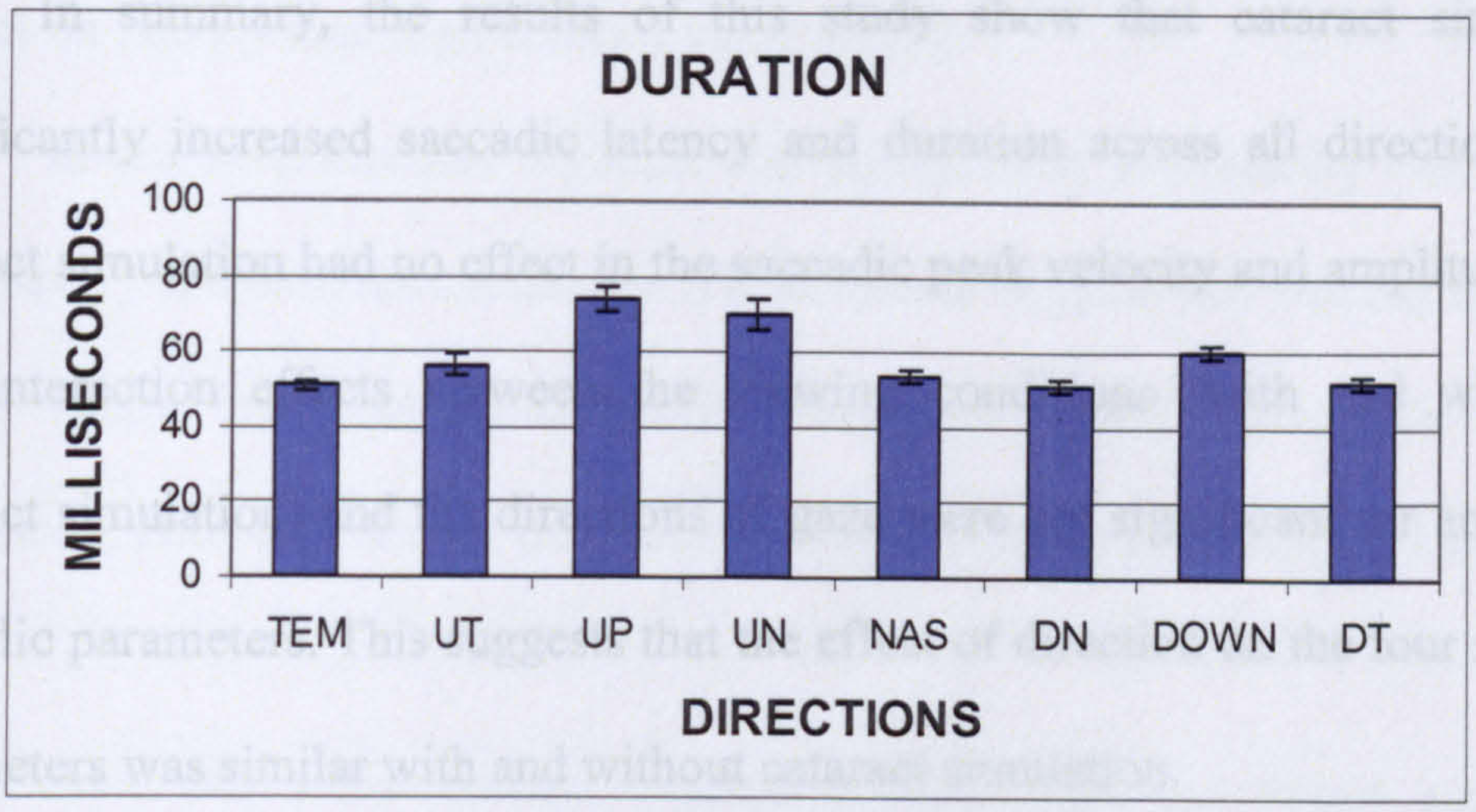


Figure 8.3.4.2: Average duration values of all observers for each direction separately when responses obtained with and without the cataract simulation were combined. The error bars are ±1 SEM.

The interaction between direction and viewing conditions is not significant ($F_{7, 133} = 0.72$, $p = 0.66$). This can be seen in Figure 8.3.4.3 that shows the average saccadic duration of twenty observers for each direction and viewing conditions respectively. The error bars are ±1 standard error of the mean.

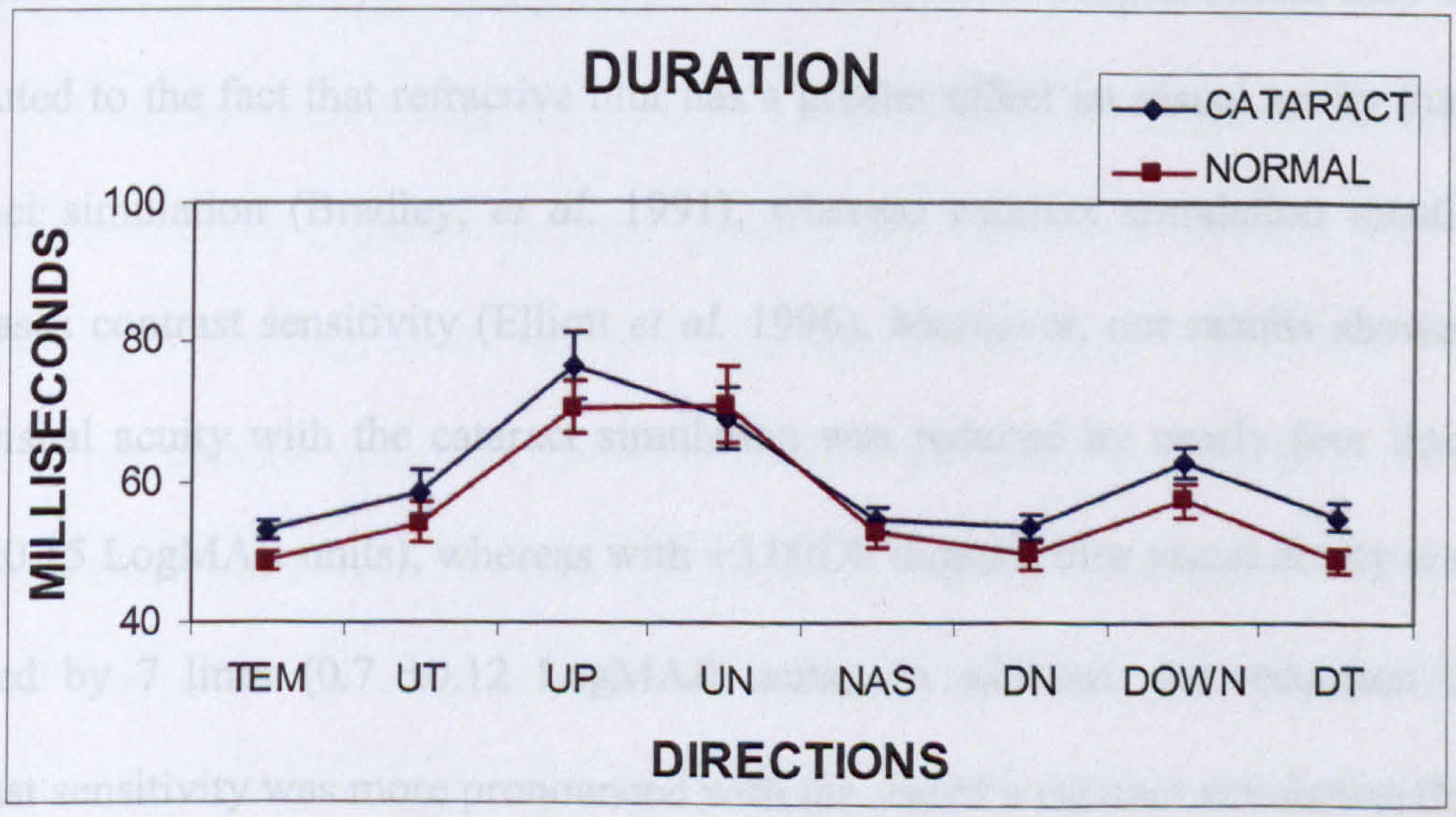


Figure 8.3.4.3: Average duration values for all observers for each direction and each viewing condition (normal versus cataract vision). The blue diamonds correspond to the durations obtained with the cataract simulation; the magenta squares correspond to the normal vision. Error bars are ±1SEM.

8.4 Discussion

In summary, the results of this study show that cataract simulation significantly increased saccadic latency and duration across all directions. The cataract simulation had no effect in the saccadic peak velocity and amplitude data. The interaction effects between the viewing conditions (with and without a cataract simulation) and the directions of gaze were not significant for any of the saccadic parameters. This suggests that the effect of direction on the four saccadic parameters was similar with and without cataract simulation.

The increased saccadic latency with the cataract simulation could be explained as the indirect effect of reduced contrast. Reductions in contrast have previously been shown to increase saccadic latency (Wheeless *et al.* 1967; Brown 1972; Haegerstrom and Brown 1979; Ludwig *et al.* 2004). However, defocus, which is also known to reduce retinal contrast, did not significantly affect latency (see Chapter 7). This discrepancy between the results obtained from this study, with cataract simulation, and the defocus data described in Chapter seven, may be attributed to the fact that refractive blur has a greater effect on visual acuity than cataract simulation (Bradley, *et al.* 1991), whereas cataract simulation mostly decreases contrast sensitivity (Elliott *et al.* 1996). Moreover, our results showed that visual acuity with the cataract simulation was reduced by nearly four lines (0.4 ±0.15 LogMAR units), whereas with +3.00DS dioptric blur visual acuity was reduced by 7 lines (0.7 ±0.12 LogMAR units). In addition, the reduction in contrast sensitivity was more pronounced with the use of a cataract simulation (by an average of 0.85 log units) than with the use of a +3.00DS blur (by an average of 0.15 log units). This effect of defocus on contrast sensitivity is similar to that found by Bradley, *et al.* (1991). Hence, the finding that latency is affected by cataract simulation and not defocus suggests that contrast sensitivity has a greater impact on latency than high contrast visual acuity.

In contrast, saccadic duration was significantly affected by both defocus (Chapter 7) and cataract simulation. These results suggest that reductions in both visual acuity and contrast sensitivity can significantly affect this saccadic parameter. Therefore it may be considered to be not as powerful as a diagnostic tool.

From our measurements of contrast sensitivity and visual acuity, our cataract simulation is equivalent to the presence of a dense cataract. Our results show that this viewing condition introduces changes in the measurements of latency and duration of saccadic eye movements. Therefore, if this methodology was used as a diagnostic and/or monitoring tool the presence of dense cataract should be considered as a factor that could affect the measurements. This is particularly important considering the diagnostic power of saccadic latency (Chapter four; Van Dongen, *et al.*1991).

Of course, these results are specific to the conditions of the experiment (i.e. double Vistech goggles). A more detailed and systematic investigation of different types and degrees of real lenticular opacity could be carried out. For example, the cataract condition could be divided and quantified in terms of a grading scale (e.g LOCSIII for details see Chylack, *et al.* 1993) or alternatively, in terms of their effect on contrast sensitivity. The results would then provide the clinician with more quantifiable information on the effect of cataract on saccadic eye movements.

CHAPTER 9:

The effect of amblyopia on the metrics of saccadic eye movements.

9.1 Introduction

In the previous Chapters of this thesis, important conditions have been investigated that may be encountered in a clinical environment (e.g. effect of residual refractive error and cataract). In addition, baseline normative data have been established on the metrics of saccadic eye movements in different directions of gaze across a wide age range.

In order to examine if this methodology is able to distinguish between normal and abnormal responses we decided to investigate the effect of amblyopia on the dynamics of saccadic eye movements. Firstly, this condition was selected due to its' high prevalence (approximately 2-2.5%) within the general population (Ciuffreda, *et al.* 1991). Secondly, a review of the literature revealed changes in various oculomotor functions (i.e. increased saccadic latencies, increased drift, abnormal smooth pursuit movements and reduced accommodative vergence) with amblyopia (Ciuffreda, *et al.* 1991) that could be detected with our recording system.

Several different definitions of amblyopia have been proposed (Ciuffreda *et al.* 1991) that are adequate in the general sense, but the absence of a common definition has produced confusion and difficulties. Consequently, Ciuffreda *et al.* (1991) proposed a new definition of amblyopia:

" *Amblyopia can be defined as a unilateral (or infrequently bilateral) condition in which the best corrected visual acuity is poorer than 20/20 in the absence of any obvious structural or pathological anomalies with one or more of the following conditions occurring before the age of 6 years: amblyogenic anisometropia, constant unilateral esotropia or exotropia, amblyogenic isometropia, amblyogenic unilateral or bilateral astigmatism and/or image degradation.*"

In a major review on amblyopia, Campos (1995) reported that the most practical classification of this condition was formulated by Von Noorden (1995). This classification is based mainly on the aetiology of amblyopia (Table 9.1). However, Campos (1995) also suggested that the classification of amblyopia is improved by taking into consideration factors such as visual (grating acuity, contrast sensitivity) (Flynn, 1991) and oculomotor (saccades, pursuit and optokinetic nystagmus) performance (McFee, *et al.* 1992).

Several studies have investigated the effect of different types of amblyopia on the several types of eye movements (fixational, saccades, smooth pursuit, vestibular-optokinetic, vergence). However, for this study, we are interested in the effect of amblyopia on the dynamics of the saccadic system (latency, peak velocity, amplitude and duration). These parameters will be discussed separately in the following sections.

Table 9.1: Classification of amblyopia proposed by Van Noorden (1995). Adapted from Campos (1995)

Causes of Amblyopia
1. Strabismus
2. Anisometropia a. *Anisohypermetropia* b. *Anisomyopia*
3. Form Vision Deprivation (amblyopia ex anopsia (uni- or bilateral) a. *Complete ptosis, media opacities, unilatelar occlusion or atropination* b. *Uncorrected bilateral high hypermetropia* c. *Astigmatism (meridional amblyopia)* d. *Nystagmus (no direct proof exists as stated by Campos, 1995)*

9.1.1 Latency

There is a general agreement that saccadic latency (reaction time) is increased in amblyopic eyes compared to fellow eyes and/or a control group (Mackensen 1958; Ciuffreda, *et al.* 1978a; Ciuffreda, *et al.* 1978b; Hamasaki and Flynn, 1981; Ciuffreda 1991).

Mackensen (1958) reported a small increase (approximately 25 msecs) in saccadic latencies of observers with constant strabismus, using a target displacement of ±15 degrees from the midline. Ciuffreda, *et al.* (1991) also reported that Gerin, *et al.* (1973) confirmed increased saccadic latencies in 60 children with functional amblyopia.

Ciuffreda, *et al.* (1978a, 1978b) recorded monocular and binocular horizontal eye movements with a range of displacements of 0.25-8.5 degrees and reported an average increase of 100 msecs in most amblyopic eyes when compared to the normal group. They investigated four different groups [(i) normals, (ii) amblyopes without strabismus, (iii) amblyopes with constant strabismus and (iv) strabismic with no-or little amblyopia] and concluded that the necessary condition for increased saccadic latencies was amblyopia and not strabismus.

Hamasaki and Flynn (1981) confirmed increased reaction times (approximately 45msecs) to a 0.25-degree light spot. They also related this increase to the presence of amblyopia and not strabismus due to the fact that the responses from the strabismic observers without ambyopia were not significantly different when compared to the normals. They also reported that increased latencies were directly related to the severity of amblyopia.

In agreement, Ciuffreda *et al.* (1991) also found a direct relationship between the depth of amblyopia and an increase in saccadic reaction times. These findings suggest that sensory rather than motor factors are involved in the higher values of saccadic latencies detected in the amblyopic eyes (Ciuffreda, *et al.* 1991).

In a study using an infrared methodology, Misura, *et al.* (1981) reported increased saccadic latencies in their amblyopic compared to normal observers for both horizontal and vertical 5° step movements. Similarly, Kato, *et al.* (1980) also found increased saccadic latencies and suggested an additional effect of direction on saccadic reaction times. They reported that the saccadic latencies for the amblyopic eyes were longer in the nasal and upward direction when compared to the temporal and down direction respectively. This investigation was limited to horizontal and vertical directions of gaze.

Schor (1975) used an infrared eye movement monitoring apparatus and investigated horizontal eye movements over a range of 15 minarc to 10 degrees. In contrast to the studies described above, he found that the mean saccadic latency of strabismic amblyopes was similar to those recorded from the control group.

9.1.2 Peak Velocity

Although the effect of amblyopia on saccadic peak velocity is not as well documented as saccadic latency, there are some studies that have revealed that amblyopic and fellow eyes show similar saccadic peak velocities to normals (Fricker, 1976; Ciuffreda, *et al.* 1991).

Fricker (1976), using an infrared recording apparatus, investigated the saccadic peak velocity and acceleration of 20-degree horizontal eye movements in three patients with strabismus. They reported that peak velocity values were within normal limits. In a study of one anisometropic amblyope without strabismus (with VA of 20/40), Cuiffreda, *et al.* (1991) reported similar peak velocities between the eyes (amblyopic versus fellow eye).

9.1.3 Amplitude

Another saccadic parameter that has been studied in relation to amblyopia is the saccadic amplitude. Some studies reported marked hypometric (undershooting) saccadic eye movements (Schor, 1975; Ciuffreda, *et al.* 1991) whereas others have suggested marked hypermetric (overshooting) saccades (Ciuffreda, *et al*, 1979a). Furthermore, Ciuffreda, *et al.* (1979b), in a preliminary study of one observer with deep amblyopia (with VA 20/630), found both hypometric and hypermetric saccadic eye movements to a five-degree step target. This latter result could be attributed to poor target visibility even though this notion was not suggested by the authors. However, they suggested that there is no established relationship between eye movement performance and visual acuity in amblyopes.

In a study where an infrared methodology was used, Schor (1975) suggested that the monocular horizontal saccadic eye movements (ranging from 15 minarc to 10 degrees) of amblyopic eyes were reduced in amplitude and were highly variable. He suggested that amblyopes use a larger retinal area to fixate when a saccade is made. Therefore, increased saccadic variability is found due to the decrease in position sensitivity within the fovea. This reduced feedback of the retinal image resulted in subsequent saccades especially in the nasal direction compared to the temporal. These findings were also attributed to an abnormal direction sense resulting from a habitual suppression in the deviating eye.

A comprehensive study on the effect of amblyopia to saccadic amplitude was made by Mackensen (1957) (cited in Ciuffreda, *et al.* 1991). In this study, they used electroculography as their eye movement recording technique and found marked undershooting of 30-degree amplitudes. Mackensen (1957) suggested that sensory disturbance leads to inaccurate eye movements in amblyopes.

In contrast, Ciuffreda, *et al.* (1979a) showed data of a patient with constant strabismic amblyopia and another patient with amblyopia but no strabismus and they reported marked overshooting during the saccadic tracking of a small amplitude measurement (0.6 degree). This finding was attributed to abnormalities in the sensory pathways that process the visual information in order to generate saccadic eye movements (Ciuffreda, *et al.* 1991).

More recently, research interest has been directed towards the effect of amblyopia (Maxwell, *et al* 1995) and strabismus (Kapoula, *et al.* 1997a, 1997b; Van Leeuwen, *et al.* 2001) on the binocular coordination of saccadic eye movements. Maxwell, *et al.* (1995), using a magnetic search coil to measure binocular performance, revealed that the horizontal saccadic eye movements (range 20°-40°) of humans with a deeply amblyopic eye were highly non-conjugate compared to their control group. They also reported that deep amblyopia was more related to this finding than strabismus.

In contrast, Kapoula, *et al.* (1997a), using an infrared monitoring eye movement methodology, investigated the impairment of binocular coordination of saccadic eye movements in humans with strabismus and mild or no amblyopia. They suggested that strabismus alone is able to deteriorate the binocular conjugacy of saccades and showed that there was not a typical pattern of disconjugacy in strabismics even though the difference in amplitudes were more marked and variable in strabismus with larger angles.

9.1.3 Duration

To our knowledge, the effect of amblyopia on the saccadic durations is not as well documented as latency. However, there is a study using a photoelectric methodology (Ciuffreda, *et al.* 1978a), where they investigated the processing delays in relation to eye movements of the amblyopic eye. The results indicated that the values of saccadic duration of different types of amblyopes were in agreement to previously published data obtained from normal observers (Bahill, *et al.* 1975). These findings provide further evidence that the effect of amblyopia on the metrics of saccadic eye movements is mainly due to sensory rather than motor factors (Ciuffreda, *et al.* 1991).

9.2 Purpose

A review of the literature has revealed that amblyopia has an effect on some saccadic parameters. Therefore, the aim of this study is to investigate the ability of this non-invasive eye movement recording technique to identify abnormal eye movement responses.

9.3 Methods

9.3.1 Stimulus/Eye movement monitoring apparatus/Recording System/ Experimental procedure/ Data Processing.

The same methodology (stimulus, apparatus, recording system, data processing) was applied in this study as previously described (Chapters Three and Four).

The experimental procedure followed in this study was similar to the one described in Chapter four. Briefly, monocular recordings of 10-degree saccadic eye movements in eight different directions of gaze (TEM, NAS, UP, DOWN, UN, DT, UT, DN) were collected. Four recordings for each direction were made and the average and standard deviation calculated. All measurements were made for the amblyopic eye and the fellow eye on two separate occasions (one day to one week interval). The non-tested eye was patched during recordings in order to exclude light completely and minimise any interference with the tested eye. For two observers (8 and 9), it was necessary to increase the size of the target (from 3 x 3 to 6 x 6 pixels) during recording from the amblyopic eye in order to improve its visibility.

9.3.2 Observers

9.3.2.1 Control group

Twenty visually normal observers were recruited from the staff and student population of the University of Bradford. Their ages ranged from 20 to 39 years (median 25.5 years). Thirteen of the observers were female.

Before the experimental procedure, all observers underwent a series of preliminary tests - cover test, motility test and stereopsis to establish that their binocular vision was normal. All observers demonstrated a TNO stereoscopic acuity better than 60 seconds of arc. Visual acuity in all observers was at least 0.0 LogMAR units. An optical correction was used if necessary (contact lenses or full aperture trial case lenses). Observers participating in the study had no systemic disease and were not under medication that is known to affect saccadic eye movements.

9.3.2.2 Amblyopes

Our observers were classified as having amblyopia if the best corrected visual acuity in one eye (amblyopic) had visual acuity less than 0.3 LogMAR units. Nine amblyopes were recruited from the student population of the University of Bradford. Their ages ranged from 20 to 40 years (median 27 years). Observers participating in the study were free from systemic disease and were not under any medication that is known to affect saccadic eye movements.

Before the experimental procedure, all observers underwent a series of preliminary tests – LogMAR visual acuity; cover test; motility test and stereopsis. The results of these tests are shown in Table 9.3.4.1. Case histories indicated that all but one (8: anisometropic amblyopia) of our observers had undergone a period of patching treatment (at least 2 hours per day) before the age of six years old. In addition, only one observer (3: alternating exotropia resulting from overcorrected esotropia) had undergone squint surgery. An optical correction was used throughout the recording sessions if necessary (contact lenses or full aperture trial case lenses).

Table 9.3.2.2: Summary details of the preliminary tests from the nine amblyopes. The blue font indicates the amblyopic eye of each observer. The observers are listed in the table from best (1) to worst (9) in terms of the visual acuity in their amblyopic eye.

Observers / Sex /Age (years	Current Rx	Visual Acuity RE/LE (LogMAR)	Stereopsis (TNO)	Cover Test (at 3m)
1 Female 20	RE→ +5.00/ –0.50x30 LE→+4.25/ –0.75x170	**RE → 0.3** LE→ 0.0	60secarc	Orthophoria
2 *(anisometropic)* Female 24	RE→ -2.00DS LE→ +2.50DS But no Rx is used	RE→ -0.2 **LE→ 0.3**	240secarc	Orthophoria
3 Male 28	RE→ +0.75DS LE→ +2.50/-1.00x70	RE→ -0.2 **LE→ 0.3**	<240secarc	Exotropia (alternating)
4 Male 27	RE→- 1.50DS LE→-2.25/–2.50x96	**RE→ 0.4** LE → -0.1	<240secarc	Orthophoria
5 Male 37	RE→-3.25/–0.50x75 LE→ -2.50DS	RE→ -0.1 **LE→ 0.6**	<240secarc	Esophoria
6 Male 32	RE→ +2.00DS LE→ plano/ –0.25x80	**RE→ 0.6** LE→ -0.3	<240secarc	Orthophoria
7 Female 26	No Rx used	RE→ -0.2 **LE→ 0.7**	<240secarc	Esotropia (10^{Δ})
8 *(anisometropic)* Male 40	RE→ -17.50DS (balance lens of –2.50DS used) LE→-2.50cyl –1.25ax25	**RE→ 0.8** LE→ -0.2	<240secarc	Orthophoria
9 ***(Deep amblyopia)*** Female 20	RE→-2.00DS LE→ -2.00DS (balance lens)	RE→-0.2 **LE→ <1.00**	<240secarc	Orthophoria

9.4 Results

For this set of data, we are interested in investigating the following comparisons:

1. Compare the (a) AE and (b) FE to the normal age-matched control.
2. Compare the AE to the FE for each amblyopic observer.
3. Compare the mean intra-subject variability (mean standard deviation) of the normal subjects with the intra-subject variability of each (a) AE and each (b) FE.

The lack of homogeneity in our amblyopic group restricts our use of statistical analysis and therefore, we chose to investigate the results of each observer separately. Also, as a result of previous statistical analysis (ANOVA /see Chapters 5/6/7/8), that indicated a significant effect of direction on the four saccadic parameters, direction of gaze was also investigated separately.

The range of normality ($\pm$ 1.96$\times$STDEV$_{group}$) was used with the purpose of comparing the mean value of a single amblyopic observer with the range of the age-matched control group. All the values that fall within this range were considered to be "normal" values.

With consideration to the limitations of parametric statistical analysis for this data set, a mixed design ANOVA was applied to the data for each saccadic parameter in order to investigate the comparisons 1a and 1b. Such analysis would be appropriate if we had been able to carefully control for the characteristics of our amblyopic observers. The results are as follows:

(1a): The mean saccadic latency ($F_{1,16} = 6.66$, p=0.02), peak velocity ($F_{1,16} = 5.43$ p=0.03) and duration ($F_{1,16} = 14.39$, p=0.002) of the AEs were significantly longer than the age-matched control group. The mean saccadic amplitude of the AEs was not significantly different to that of the control group ($F_{1,16} = 0.73$, p=0.41).

(1b): The mean saccadic latency ($F_{1,16} = 0.67$, p=0.425), peak velocity ($F_{1,16} = 2.82$, p=0.11) and amplitude ($F_{1,16} = 0.052$, p=0.82) of the FEs showed no significant differences to those recorded from the age-matched control group. The mean saccadic duration was significantly longer ($F_{1,16} = 12.83$, p=0.002) than that of the control group by an average of 14 msecs.

In addition, a repeated measures ANOVA was applied to all four saccadic parameters in order to compare the mean values of the AEs to that of the FEs (2). The statistical analysis revealed that the AEs had significantly longer ($F_{1,8} = 6.13$, p=0.04) mean latencies than the FEs by an average of 76 msecs. For the other three saccadic parameters (*peak velocity*: $F_{1,8} = 1.00$, p=0.35; *amplitude*: $F_{1,8} = 3.65$, p=0.09; *duration*: $F_{1,8} = 0.265$, p=0.62), the differences between the mean values of the AEs and the FEs were not significant.

Data for the AEs and FEs are plotted for the four saccadic parameters separately (Figures 9.4.1.1-9.4.4.2). The open symbols are the average values of four measurements for the AEs and the closed symbols are the same for the FEs. The error bars are ±1 standard deviation. The blue solid line shows the mean value (latency, peak velocity, amplitude or duration) for the age-matched control group, whereas the blue dashed lines indicate the 95% confidence limits ($1.96 \times STDEV_{group}$).

9.4.1 Latency

Figures 9.4.1.1-9.4.1.2 show the latency data for the eight directions of gaze. These figures show, that for all directions, the saccadic latencies recorded from the FEs of all observers fall within the normal range. In addition, the latency values recorded from the AEs of all observers, are either similar or longer than those recorded from the corresponding FEs.

When comparing the AEs with the normal control data, there is a trend for latency values to increase with worsening acuity of the AE. For example, observer 9, who has the worst visual acuity, shows latency values in her AE that are longer than normal in all eight directions. These differences vary with direction of gaze, from 134 msecs in the up-nasal direction to 1088 msecs in the temporal direction. For this observer, the most pronounced effect was for saccades to the temporal field of view (TEM, UT and DT). Observers 8 and 7, who have the next poorest acuity (0.8 and 0.7 logMAR respectively), show latencies that are longer than the normal range in four and three directions respectively. However, no consistent pattern can be observed.

In contrast, the latency values recorded from the AEs of observers 1, 2, 3, 4 and 6, are all within the normal range. The visual acuity values recorded from the AEs of these observers are 0.3 logMAR (Observers 1 – 3), 0.4 logMAR (observer 4) and 0.6 logMAR (observer 6). Observer 3 was the only strabismic amblyope of these four observers (see Table 9.3.2.2).

The data also show that there are no consistent differences in intra-subject variability between the AEs and the age-matched control group. There were amblyopes who showed smaller or similar variabilities to the control group in some directions of gaze and larger variabilities in others. The observer with the deepest level of amblyopia (Observer 9) displayed the largest intra-subject variability (more than double) in the majority of directions. However, even for this observer, the variabilities in two directions (NAS and UN) were similar to normal.

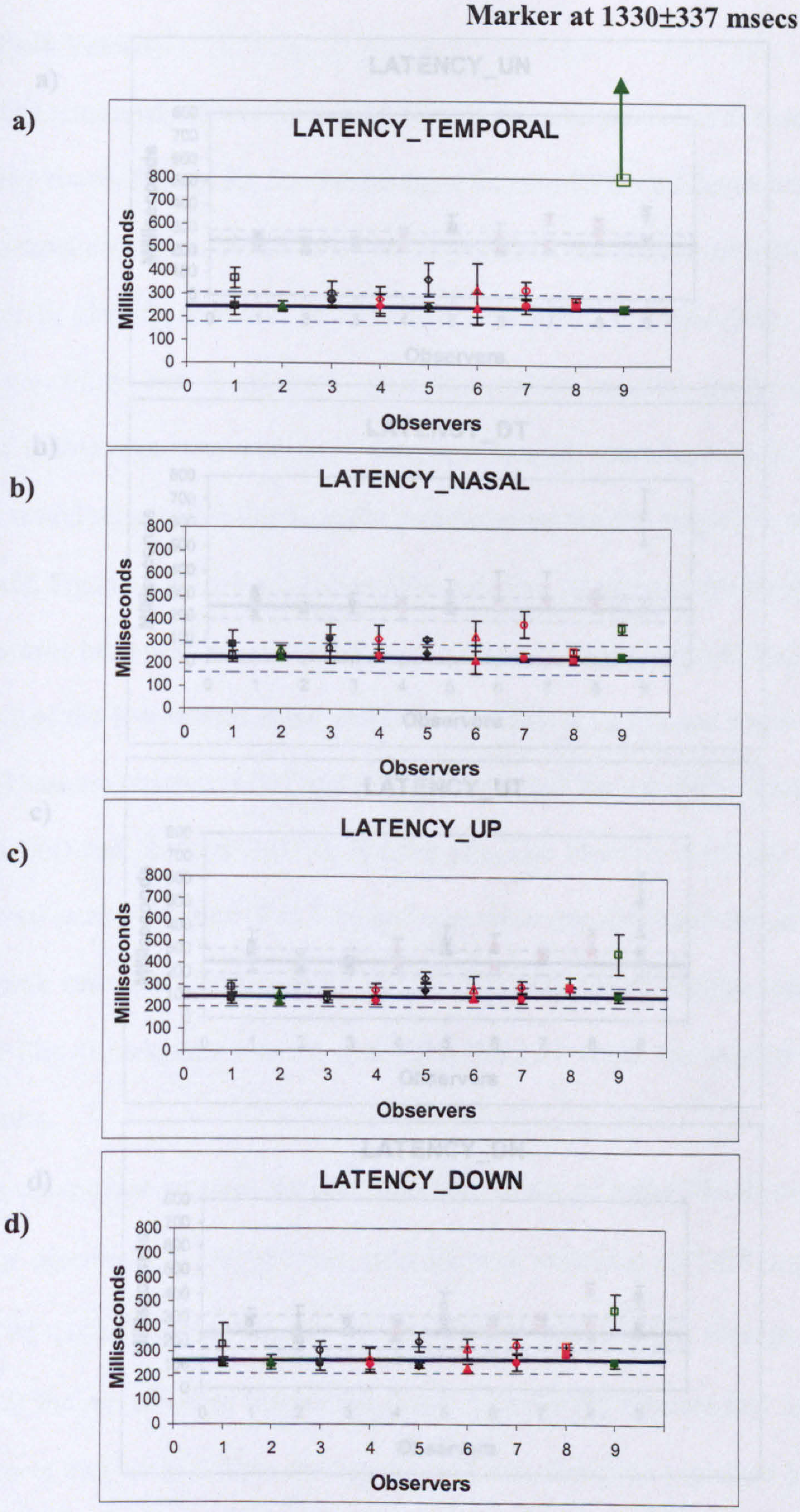


Figure 9.4.1.1: Average latency for each observer in the (a) temporal, (b) nasal, (c) up and (d) down directions. The open symbols represent the AEs whereas the closed symbols represent the FEs. The error bars indicate ± 1 STDEV. In addition, the blue solid line shows the mean of the age-matched control group and the blue dashed lines show the 95% confidence limits.

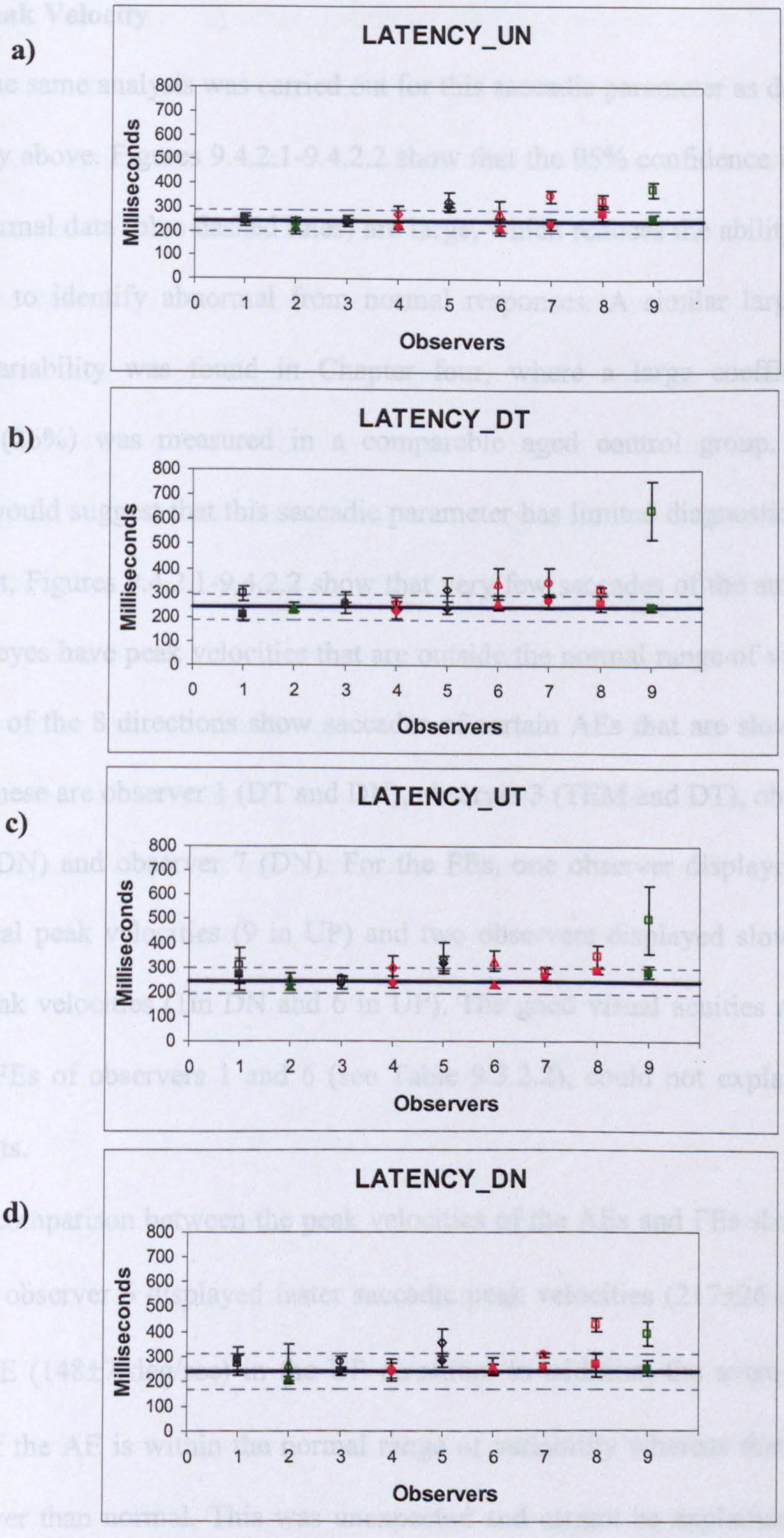


Figure 9.4.1.2: Average latency for each observer in the (a) the UN, (b) DT, (c) UT and (d) DN directions. The open symbols represent the AEs whereas the closed symbols represent the FEs. The error bars indicate ± 1 STDEV. In addition, the blue solid line shows the mean of the age-matched control group and the blue dashed lines show the 95% confidence limits.

9.4.2 Peak Velocity

The same analysis was carried out for this saccadic parameter as described for latency above. Figures 9.4.2.1-9.4.2.2 show that the 95% confidence intervals for the normal data (blue dashed lines) are large, which reduces the ability of this parameter to identify abnormal from normal responses. A similar large inter-subject variability was found in Chapter four, where a large coefficient of variation (26%) was measured in a comparable aged control group. These findings would suggest that this saccadic parameter has limited diagnostic power. As a result, Figures 9.4.2.1-9.4.2.2 show that very few saccades of the amblyopic or fellow eyes have peak velocities that are outside the normal range of variation. Only four of the 8 directions show saccades of certain AEs that are slower than normal. These are observer 1 (DT and DN), observer 3 (TEM and DT), observer 4 (UN and DN) and observer 7 (DN). For the FEs, one observer displayed faster than normal peak velocities (9 in UP) and two observers displayed slower than normal peak velocities (1in DN and 6 in UP). The good visual acuities recorded from the FEs of observers 1 and 6 (see Table 9.3.2.2), could not explain these latter results.

A comparison between the peak velocities of the AEs and FEs shows that the AE of observer 6 displayed faster saccadic peak velocities (217±26 deg/sec) than his FE (148±7 deg/sec) in the UP direction. In addition, the average peak velocity of the AE is within the normal range of variability whereas that for the FE is slower than normal. This was unexpected and cannot be explained by his visual acuity in the AE (0.6 logMAR) compared to the FE (-0.3 logMAR) or the intra-subject variability. All other directions for this observer show data that is within the normal range for both the AE and FE.

In conclusion, the results obtained from this saccadic parameter support the previous reports that its diagnostic power is limited due to an increased range of variation within the control group. In the majority of observers and directions the responses from our amblyopic group were not identified as abnormal. Although there were a few occasions whereby the peak velocities in either the AEs and/or the FEs were different from normal, no specific pattern was identified, either within or between observers. In addition, the AEs did not show a consistent pattern of increased variability compared to the normal data as was expected. No specific relation between increased variability and the type or severity of amblyopia was detected since there were observers who showed increased variability in some directions and decreased in others.

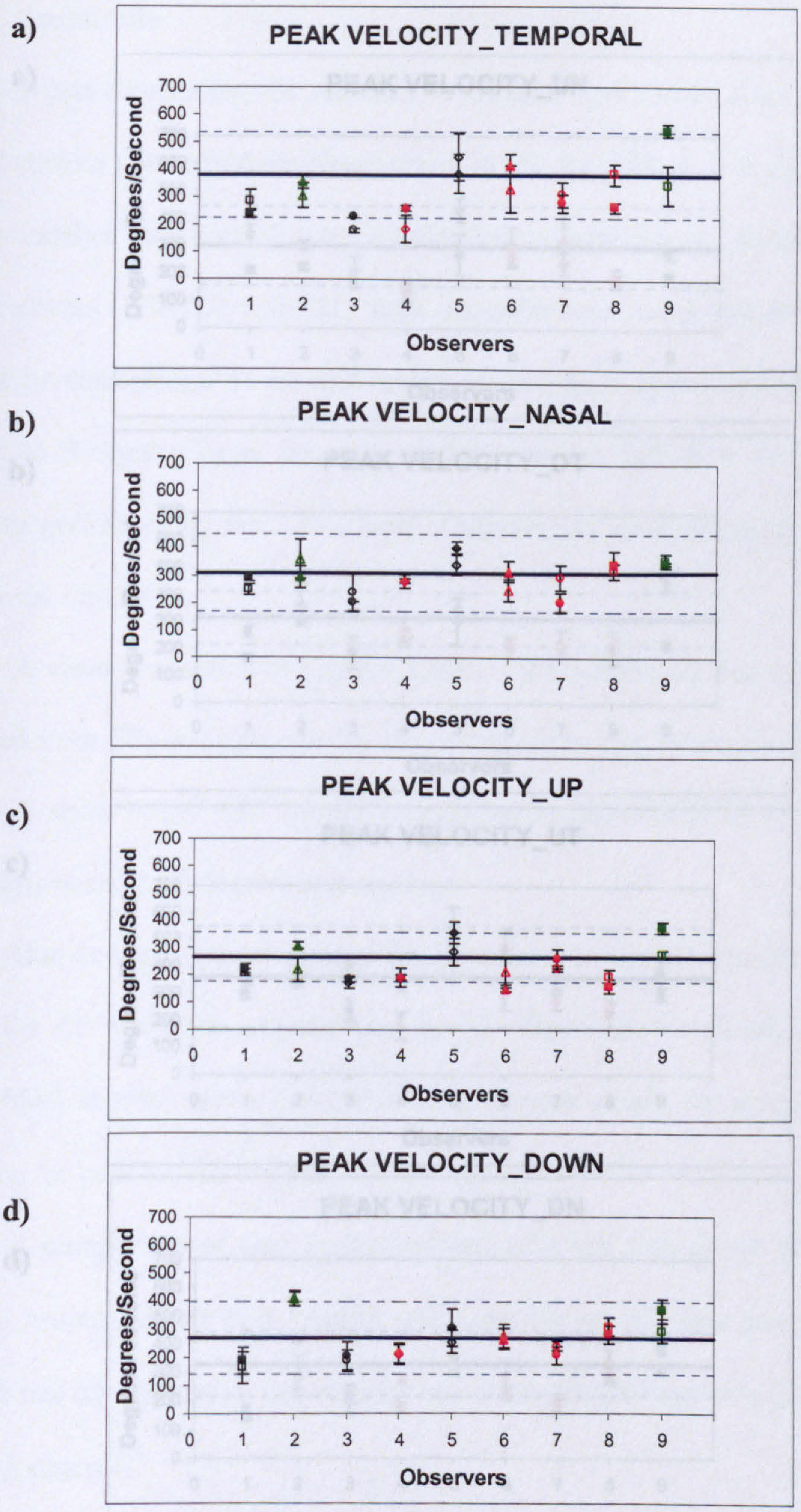


Figure 9.4.2.1: Average peak velocity for each observer in the (a) temporal, (b) nasal, (c) up and (d) down directions. The open symbols represent the AEs whereas the closed symbols represent the FEs. The error bars indicate ± 1 STDEV. In addition, the blue solid line shows the mean of the age-matched control group and the blue dashed lines show 95% confidence limits (range of variation).

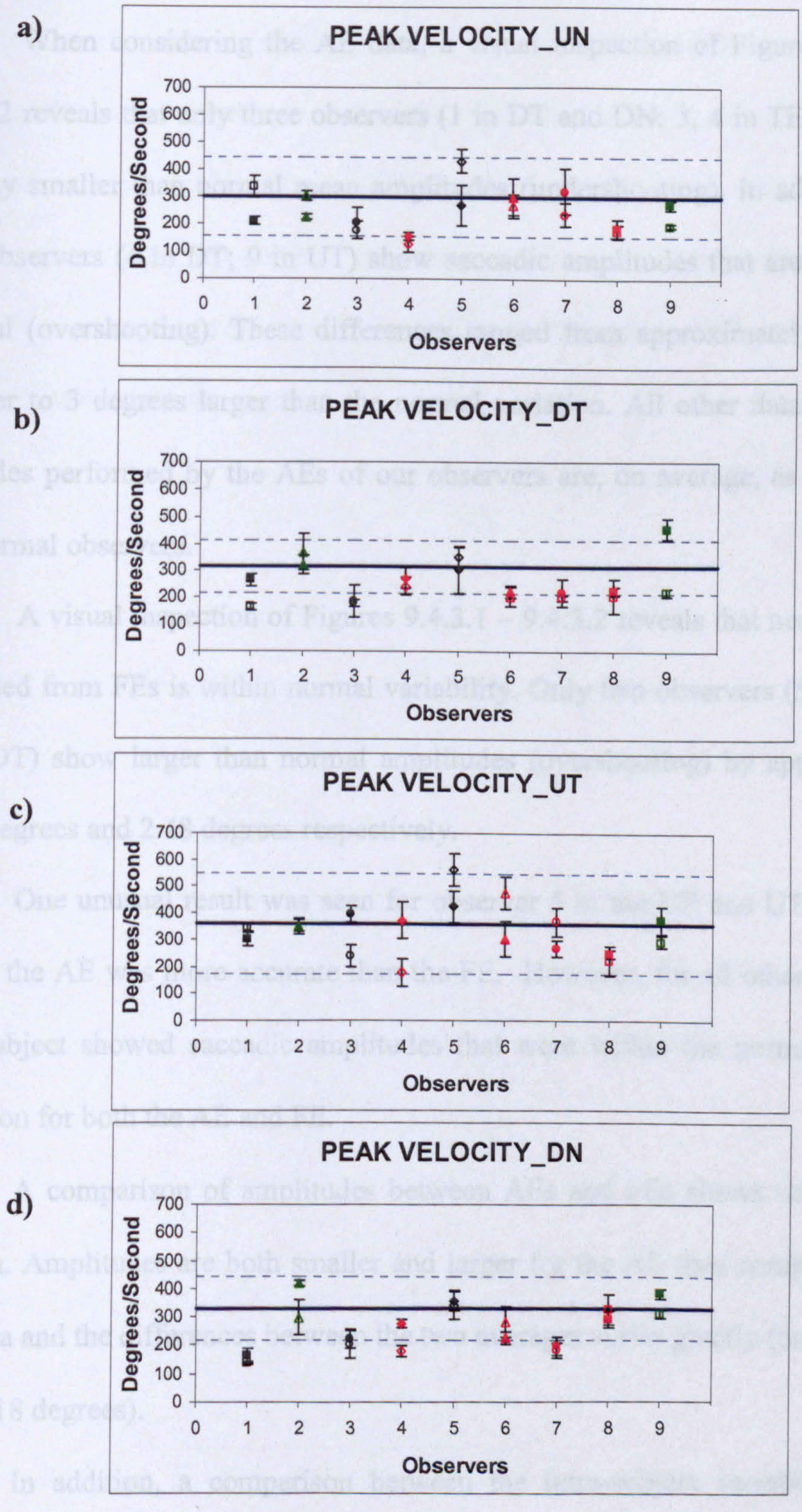


Figure 9.4.2.2: Average peak velocity of each observer in the (a) the UN, (b) DT, (c) UT and (d) DN directions. The open symbols represent the AEs whereas the closed symbols represent the FEs. The error bars indicate ± 1 STDEV. In addition, the blue solid line shows the mean of the age-matched control group and the blue dashed lines show 95% confidence limits (range of variation).

9.4.3 Amplitude

When considering the AE data, a visual inspection of Figures 9.4.3.1 – 9.4.3.2 reveals that only three observers (1 in DT and DN; 3, 4 in TEM and UN) display smaller than normal mean amplitudes (undershooting). In addition, only two observers (4 in DT; 9 in UT) show saccadic amplitudes that are larger than normal (overshooting). These differences ranged from approximately 4 degrees smaller to 3 degrees larger than the normal variation. All other data shows that saccades performed by the AEs of our observers are, on average, as accurate as the normal observers.

A visual inspection of Figures 9.4.3.1 – 9.4.3.2 reveals that nearly all data recorded from FEs is within normal variability. Only two observers (5 in UP and 4 in DT) show larger than normal amplitudes (overshooting) by approximately 4.83 degrees and 2.48 degrees respectively.

One unusual result was seen for observer 5 in the UP and UT directions, where the AE was more accurate than the FE. However, for all other directions, this subject showed saccadic amplitudes that were within the normal range of variation for both the AE and FE.

A comparison of amplitudes between AEs and FEs shows no consistent pattern. Amplitudes are both smaller and larger for the AE data compared to the FE data and the differences between the two averages varies greatly (between 0.05 and 4.18 degrees).

In addition, a comparison between the intra-subject variability of the recordings from each AE and the mean intra-subject variability of the age-matched control group in this saccadic parameter revealed no consistent pattern.

There were amblyopes who had higher intra-subject variabilities in some directions and lower or similar to control group variabilities in others. Only observer 8, an anisometropic amblyope, showed intra-subject variabilities that were more than double those of the control group in all directions under investigation. The intra-subject variability values recorded for the FE of our amblyopic observers were smaller or similar to the mean variability of the age-matched control group.

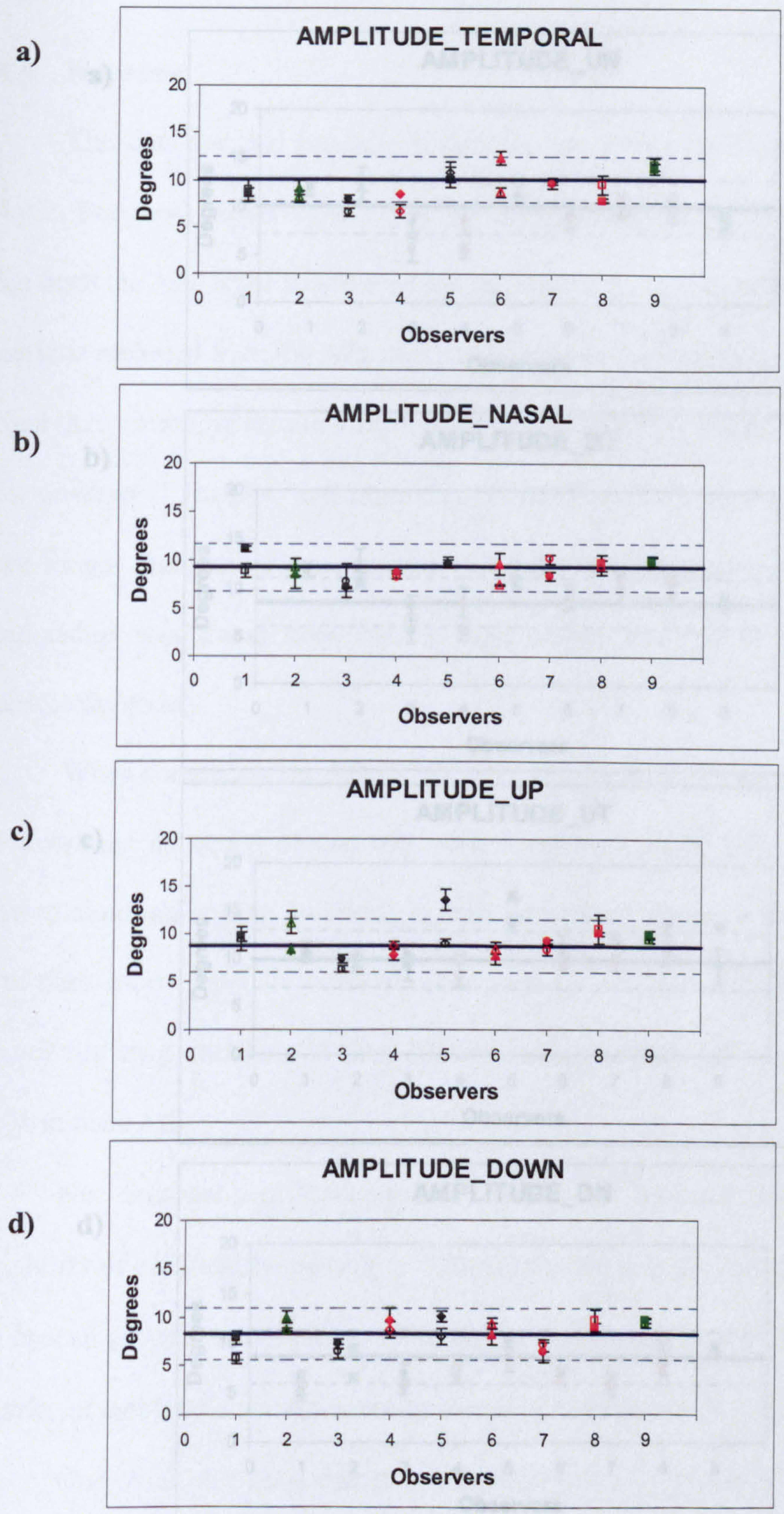


Figure 9.4.3.1: Average amplitude for each observer in the (a) temporal, (b) nasal, (c) up and (d) down directions. The open symbols represent the AEs whereas the closed symbols represent the FEs. The error bars indicate ± 1 STDEV. In addition, the blue solid line shows the mean of the age-matched control group and the blue dashed lines show the range of variation (95% confidence limits).

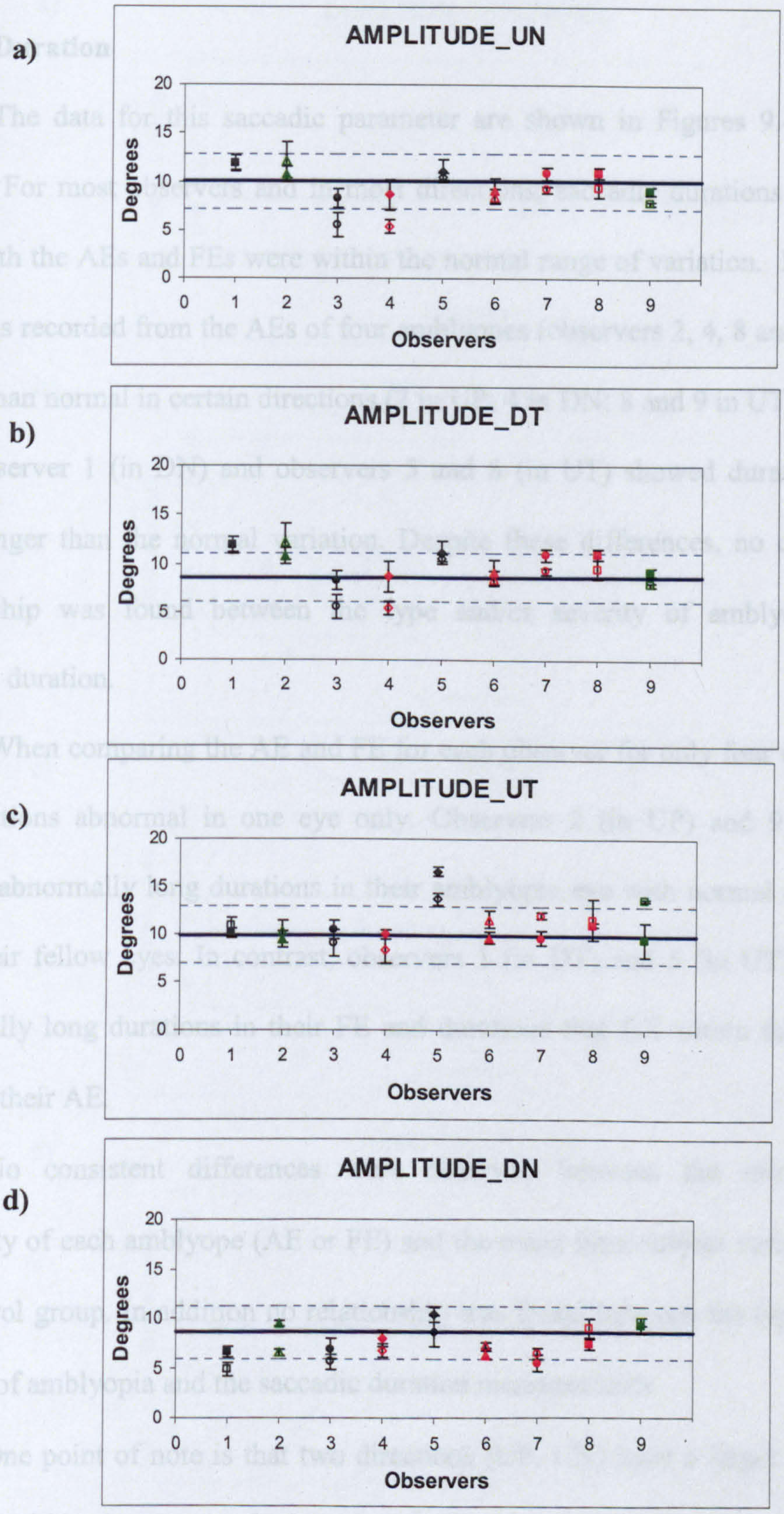


Figure 9.4.3.2: Average amplitude of each observer in (a) the vertical up direction and (b) down direction.. The open symbols represent the AEs whereas the closed symbols represent the FEs. The error bars indicate ± 1 STDEV. In addition, the blue solid line shows the mean of the age-matched control group and the blue dashed lines show the range of variation (95% confidence limits).

9.4.4 Duration

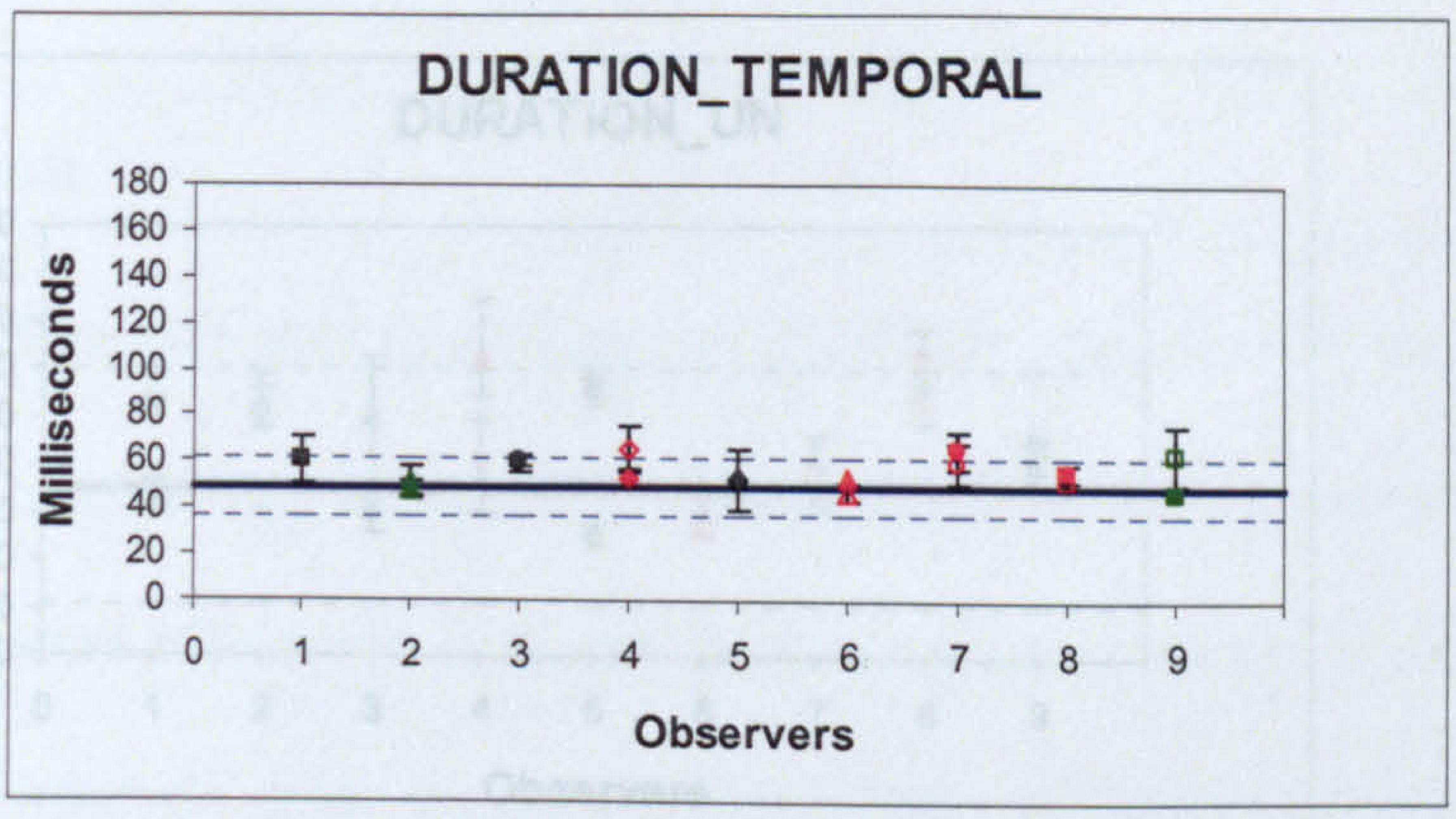
The data for this saccadic parameter are shown in Figures 9.4.4.1 and 9.4.4.2. For most observers and in most directions, saccadic durations recorded from both the AEs and FEs were within the normal range of variation. However, durations recorded from the AEs of four amblyopes (observers 2, 4, 8 and 9) were longer than normal in certain directions (2 in UP; 4 in DN; 8 and 9 in UT). For the FEs, observer 1 (in DN) and observers 5 and 8 (in UT) showed durations that were longer than the normal variation. Despite these differences, no consistent relationship was found between the type and/or severity of amblyopia and saccadic duration.

When comparing the AE and FE for each observer for only four observers are durations abnormal in one eye only. Observers 2 (in UP) and 9 (in UT) showed abnormally long durations in their amblyopic eye with normal durations from their fellow eyes. In contrast, observers 1 (in DT) and 5 (in UT) showed abnormally long durations in their FE and durations that fall within the normal range in their AE.

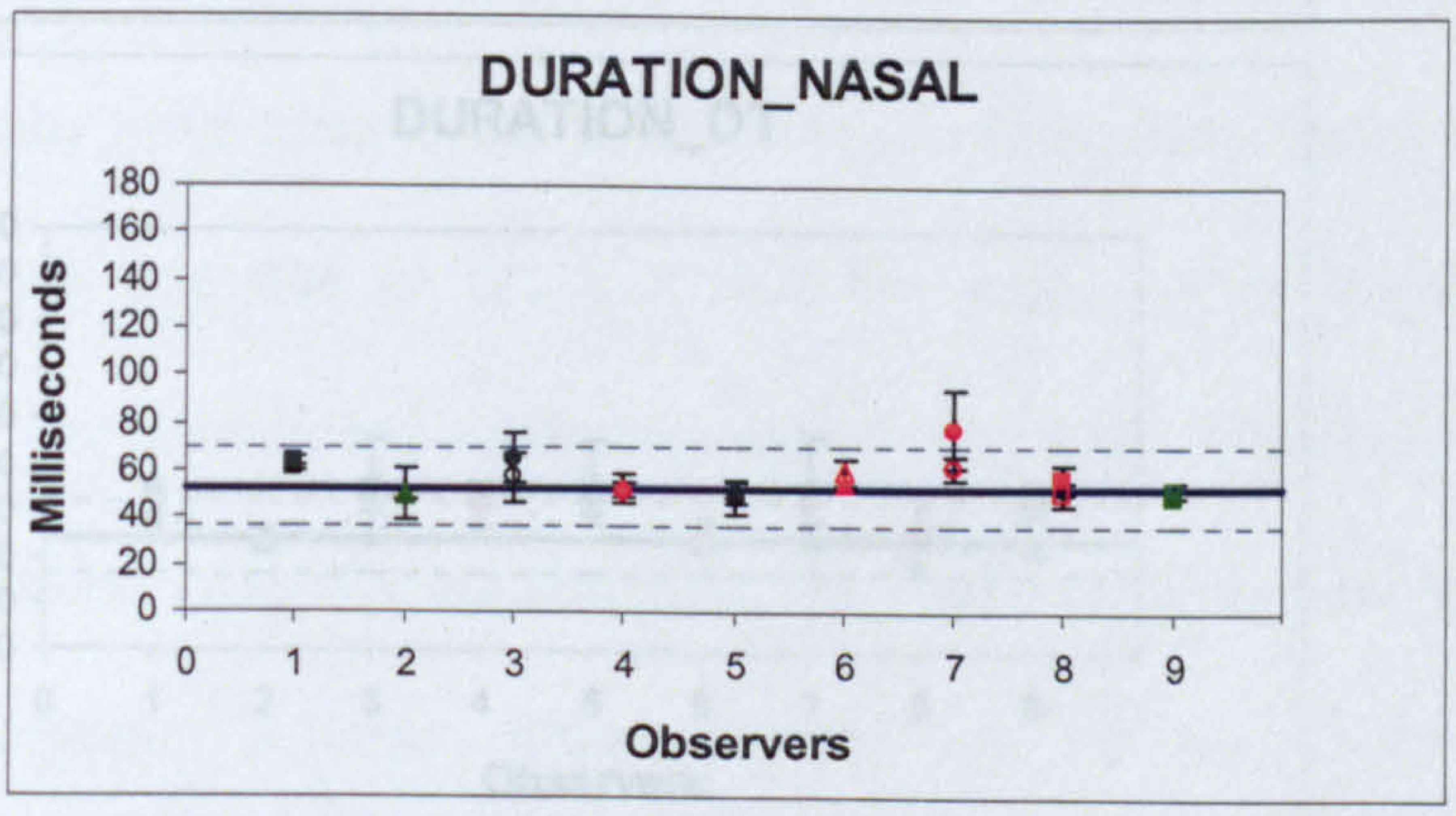
No consistent differences were observed between the intra-subject variability of each amblyope (AE or FE) and the mean intra-subject variability of the control group. In addition no relationship was found between the type and/or severity of amblyopia and the saccadic duration measurements.

One point of note is that two directions (UP, UN) have a larger range of variation within the age-matched control group compared to the other directions. Therefore the diagnostic value of saccadic duration in these directions is reduced.

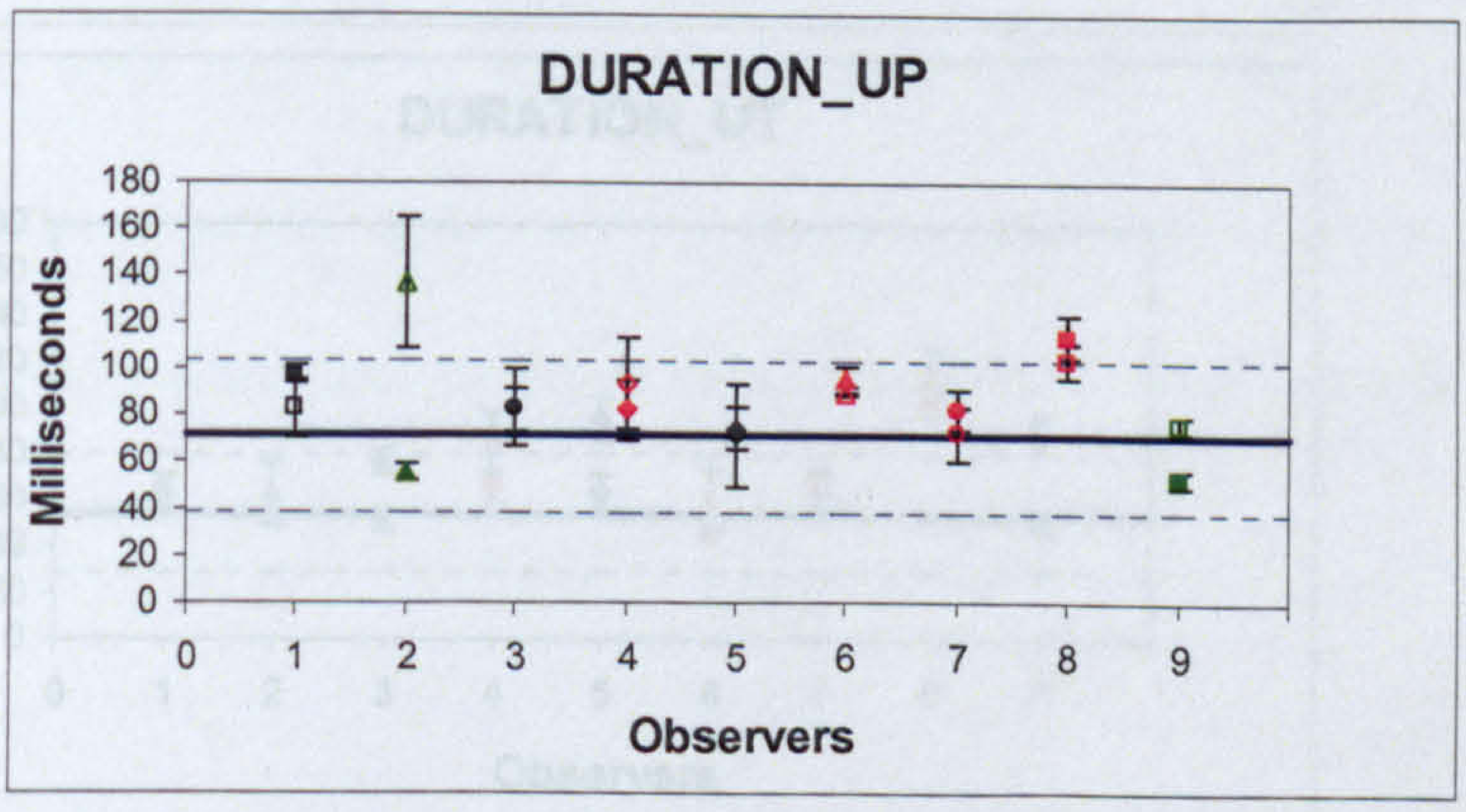
a)



b)



c)



d)

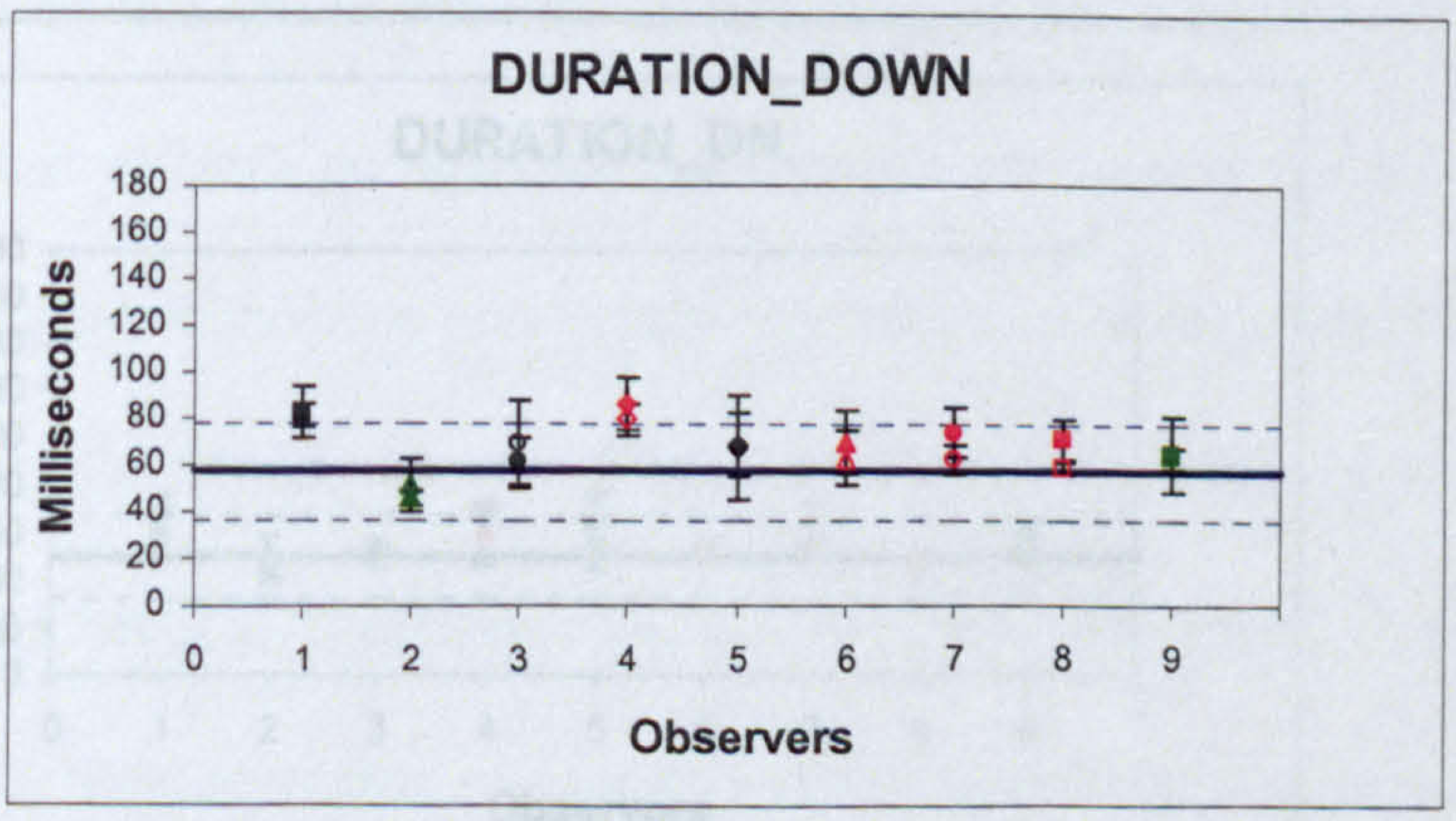


Figure 9.4.4.1: Average duration of each observer in the (a) temporal (b) nasal, (c) up and (d) down directions. The open symbols represent the AEs whereas the closed symbols represent the FEs. The error bars indicate ± 1 STDEV. In addition, the blue solid line shows the mean of the age-matched control group and the blue dashed lines show the range of variation (95% confidence limits) of saccadic duration.

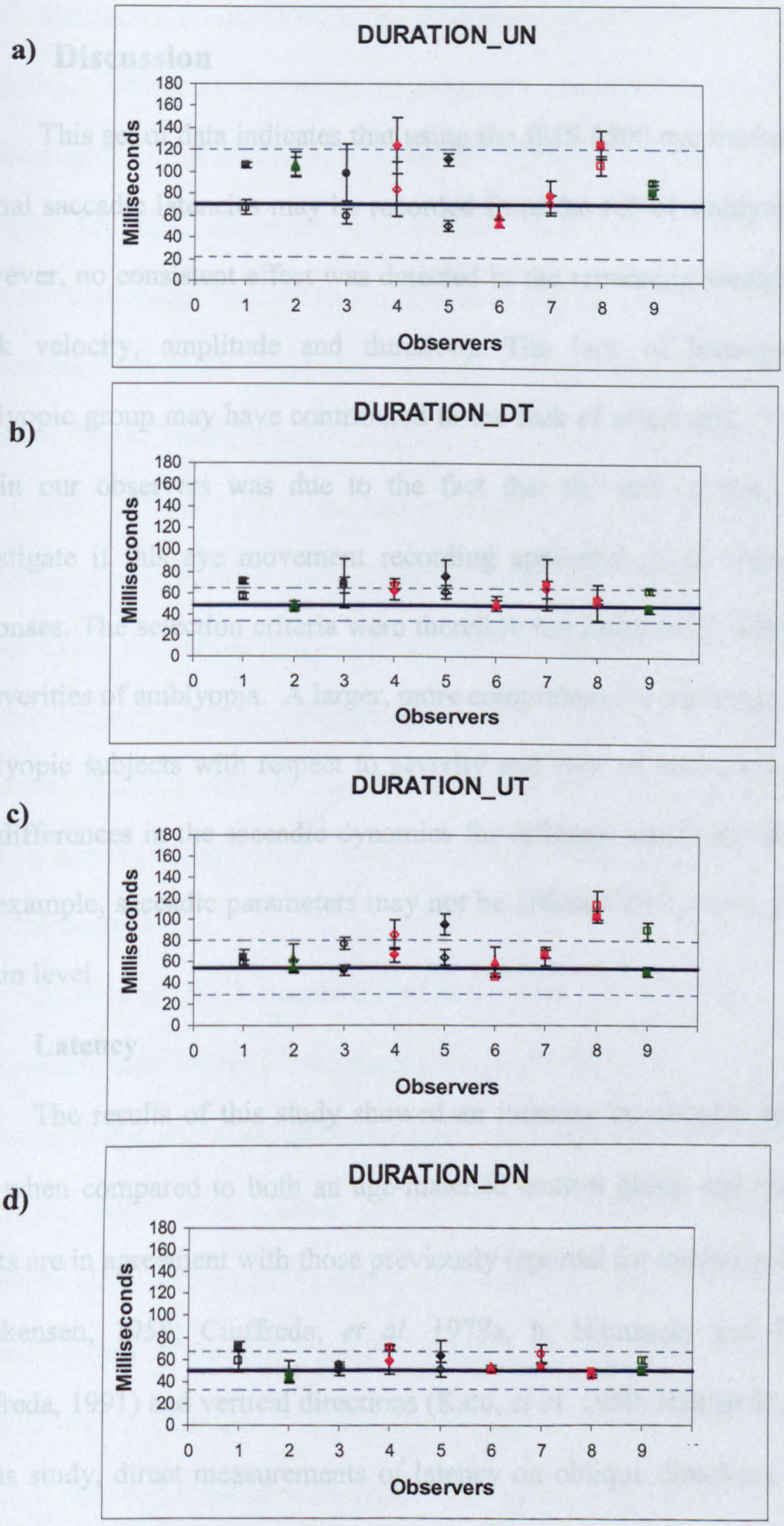


Figure 9.4.4.2: Average duration for each observer in the (a) UN (b) DT, (c) UT and (d) DN directions. The open symbols represent the AEs whereas the closed symbols represent the FEs. The error bars indicate ± 1 STDEV. In addition, the blue solid line shows the mean of the age-matched control group and the blue dashed lines show the range of variation (95% confidence limits) of saccadic duration.

9.5 Discussion

This set of data indicates that using the IRIS 6500 eye tracker, longer than normal saccadic latencies may be recorded from the AE of amblyopic observers. However, no consistent effect was detected in the remaining saccadic parameters (peak velocity, amplitude and duration). The lack of homogeneity in the amblyopic group may have contributed to the lack of effect seen. This variability within our observers was due to the fact that the aim of this study was to investigate if this eye movement recording apparatus could identify abnormal responses. The selection criteria were therefore not restricted to certain types and or severities of amblyopia. A larger, more comprehensive study could classify the amblyopic subjects with respect to severity and type of amblyopia and identify any differences in the saccadic dynamics for different amblyopic characteristics. For example, saccadic parameters may not be affected until acuity drops below a certain level.

9.5.1 Latency

The results of this study showed an increase in saccadic latency for the AEs when compared to both an age-matched control group and the FEs. These results are in agreement with those previously reported for the horizontal direction (Mackensen, 1958; Ciuffreda, *et al.* 1978a, b; Hamasaki and Flynn, 1981; Ciuffreda, 1991) and vertical directions (Kato, *et al.* 1980; Hamasaki, *et al.* 1981). In this study, direct measurements of latency on oblique directions of gaze also reveal increased latencies in some amblyopic observers compared to normal variation.

Hamasaki *et al.* (1981) and Ciuffreda *et al.* (1991) reported a direct relationship between the severity of amblyopia and saccadic latency. The results of observer 9 in this study, who is the one with the deepest level of amblyopia amongst the nine observers used, agree with this report. This observer demonstrated longer reaction times with both her AE and FE when compared to the control mean in all directions, but with a more pronounced difference in the temporal field of view (TEM, UT, DT).

Two of our observers had strabismic amblyopia (3: exotropia, 7: esotropia). The saccadic latencies recorded from both the AE and FE of observer 3 were within the normal range of variation. This result is in agreement with those reported by Schor (1975), using an infrared eye movement technique. Recording horizontal saccades only, he reported that strabismic amblyopes (two esotropes and two exotropes) had normal latencies in their AEs for predictable target steps up to ten degrees.

In contrast, the latencies recorded from the AE of observer 7 (esotrope), were significantly longer for the nasal (NAS) and up-nasal (UN) directions when compared to the normal range of variation. It is commonly reported that esotropic amblyopes have either absent or abnormal optokinetically elicited pursuit movements, but only when the stimulus moves in the temporal direction. The re-fixation saccade of the optokinetic nystagmus (OKN) is not affected for either direction (Von Noorden, 1995). The effect we found in observer 7 would therefore need to be found consistently in more observers to be considered more than just a chance occurrence.

The contradictory results between our study and that of Schor (1975) are limited only to esotropic amblyopes. Unfortunately, the information about the observers in Schor's study, is limited to the visual acuity range of the group and whether an individual is esotropic or exotropic. This restricts our ability to directly compare between studies, and as such we can only speculate that the differences found could be due to specific characteristics of the amblyopic observers. In addition, the way of defining the start of a saccadic eye movement could also affect the results. This information was not included in Schor's study (1975). Other aspects, such as the eye movement recording methodology (infrared) and the task (predictable target steps of ten degrees) were comparable. A further study involving more observers is needed to resolve this matter.

Finally, the increased saccadic latencies found for our amblyopic observers could be attributed to the reduced target visibility in the periphery. Although target visibility for the central field of view was confirmed prior to any recordings, reduced peripheral acuity could reduce visibility enough to subsequently increase reaction times. In addition, it has been reported that amblyopic observers have slower than normal visual processing along the sensory pathways that are used by the oculomotor system in order to generate saccades (Ciuffreda, *et al.* 1978a; 1991). This would result in longer than normal saccadic latencies.

9.5.2 Peak velocity

This set of data revealed limited clinical suitability of peak velocity due to a high range of variation within the normal age-matched control group. This result is in agreement with findings reported in Chapter four of a large coefficient of variation (26%) for data from a normal similarly aged group. Therefore, as expected, the majority of directions and observers reported in our study show that saccades made in the AEs and FEs had similar peak velocities to those made from the age-matched control group.

To our knowledge, there are no direct comprehensive studies that have compared peak velocities from the AE and FE to age-matched controls (Ciuffreda, *et al.* 1991). However, there is some preliminary work that is limited to small subject numbers (n=1 – n=3). They agree that saccadic peak velocities in one anisometropic amblyope (Ciuffreda, *et al.* 1991) and three strabismic observers with little or no amblyopia (Fricker, 1976) are within normal limits. These results suggest that different types and levels of amblyopia do not have an effect on the motor control of saccadic eye movements.

9.5.3 Amplitude

The results of this study showed that the majority of our observers achieved saccadic amplitudes within the normal range of variation of the age-matched control group with their AEs and FEs in the horizontal directions. In contrast, Ciuffreda *et al.* (1979b), using a photoelectric technique, investigated the effect of amblyopia on different groups with and without amblyopia (i. amblyopia without strabismus, ii. intermittent strabismus and iii. constant strabismic amblyopia). They reported overshooting during the saccadic tracking of a 0.26-degree stimulus. This disagreement between the two studies may be attributed to different methodology (different eye movement recording technique, target size and different sample size).

Furthermore, one of our strabismic amblyopes (observer 3: alternating exotropia) showed less accurate (smaller/hypometric amplitudes) in the temporal direction with his AE when compared to either the control group or his FE. In the nasal direction, the saccadic amplitudes were within the normal variation. This result is in agreement to those reported by Schor (1975) using an infrared technique. Who found that for targets moving temporally, amblyopic eyes show less accurate tracking (series of small and variable saccades) compared to those moving in the nasal direction. This result could be attributed to reduce position sensitivity extending from the fovea to the nasal hemiretina that has been reported in strabismic amblyopes (Schor and Flom, 1975).

In addition, Ciuffreda, *et al.* (1979e) reported both hypermetric (overshooting) and hypometric (undershooting) saccadic amplitudes in one observer with deep amblyopia in the horizontal direction with a target step ± 5 degrees. This inconsistency could be attributed to the reduced feedback of the retinal image observed in amblyopes (Schor, 1975). In our study, observer 9, who has the most severe level of amblyopia between our observers, showed a similar effect [hypermetric (overshooting) and hypometric (undershooting) saccades] in some of the oblique directions (UN, DT and UT) of gaze rather than the horizontal ones.

Although differences were identified in some directions and observers, no specific pattern of how amblyopia affects saccadic amplitude was identified. Another observation that was made from this set of data was that the control group has a tendency to undershoot in all the directions with a downward component. This is in agreement to previous findings in this thesis (Chapter four).

9.5.4 Duration

When considering the data from the age-matched controls, the directions with an upward component (UP, UN) had a higher range of variation than the remaining directions of gaze under investigation. This result indicated that the diagnostic power of saccadic duration in these particular directions is reduced compared to the other directions.

In the majority of directions, observers had saccadic durations similar to the ones attained by the age-matched control group. These results are in agreement to the reports of a study that used a photoelectric technique (Ciuffreda, *et al.* 1978a). They investigated the processing delays in relation to eye movements of the AE and indicated that the values of saccadic duration of different types of amblyopes were similar to previously published data obtained from normal observers (Bahill, *et al.* 1975).

9.6 Conclusion

In summary, these results indicate that this non-invasive eye movement recording technique could detect abnormal saccadic parameters in some directions and observers but due to lack of homogeneity within the amblyopic group, no specific pattern could be identified. This data set could be used as a part of a more comprehensive study of saccadic parameters using an infrared eye tracker.

Another aspect that was investigated qualitatively due to the non-homogeneous group of observers was the intra-subject variability. Overall, there is no consistent pattern of variability for the measurements from AEs when compared to those from an age-matched control group for all four saccadic parameters under investigation. There was also no consistent relationship between the type and/or severity of amblyopia and intra-subject variability of peak velocity and duration measurements. However, when considering the variability of latency values, the amblyope (observer 9) with the worst level of acuity, showed the largest amount of intra-subject variability of all amblyopic observers. Similarly, the one anisometropic amblyope (observer 8) showed larger variability of duration values compared to the other amblyopic observers and age-matched controls. These two examples may suggest that acuity and/or type of amblyopia may affect individual responses. However, more subjects are required before any relationships can be confirmed.

CHAPTER 10:

General Discussion

This thesis has investigated the clinical usefulness of a non-invasive eye movement recording technique. Saccadic eye movements are increasingly becoming a very important research tool since their parameters exhibit consistent patterns that enable researchers to quantify, identify and/or monitor several abnormalities including visual neglect, multiple sclerosis, Graves' disease, myotonic dystrophy, etc (Sweeney *et al.* 2002). In a clinical environment, a good test should be accurate, valid, repeatable, quick and yet simple to use.

Chapter four investigated the minimum number of repeated measurements required to maintain adequate precision. The primary and secondary analyses indicated that the average of four measurements provided representative measures of saccadic latency, peak velocity, amplitude and duration for a 10-degree saccade in different directions of gaze across a wide age range. This study also indicated that these saccadic parameters show no sequential trend due to fatigue, changes in attention or learning; over a ten measurement recording session. In agreement with results by Van Dongen, *et al.* (1991), the values of the coefficients of variation indicated that saccadic latency (coefficient of variation 12%-15%) appears to possess better diagnostic power when compared to peak velocity (coefficient of variation 26%-30%) in all age groups. Results also suggested that even though saccadic duration appears to have limited diagnostic value in the elderly due to its high coefficient of variation (33%), it might be informative in the investigation of young (21%) or middle-aged observers (21%). Similarly, the coefficients of variation for saccadic amplitude varied from 19% to 21% suggesting that it could also provide useful information. The test-retest repeatability of the infrared eye tracker was also investigated using the coefficient of repeatability ($\pm$ 1.96*STDEV$_{Difference}$) as suggested by Bland and Altman (1986). Table 10.1 summarizes the mean coefficient of repeatability results of this study in the three age groups. All the means show a slight increase with aging indicating that when measuring eye movements on more than one occasion it is important to consider age specific values of repeatability in any decision of functional change. Overall these results suggested that this non-invasive eye movement recording apparatus gives statistically repeatable results for centrifugal saccades to ten degrees. As stated above, good repeatability is a prerequisite for clinical use.

Table 10.1: Summary of mean coefficient of repeatability in each age group.

MEAN COEFFICIENT OF REPEATBILITY			
	20- 39 years Group I	**40- 59 years Group II**	**60- 80 years Group III**
LATENCY (msecs)	**±25**	**±40**	**±48**
PEAK VELOCITY (deg/sec)	**±107**	**±125**	**±140**
AMPLITUDE (degrees)	**±1.66**	**±1.82**	**±2.17**
DURATION (msecs)	**±17**	**±26**	**±28**

Chapter five investigated the effect of ageing and direction of gaze on the dynamics of normal saccadic eye movements. This study enabled us to establish normative data on the saccadic parameters in all eight directions of gaze using a non-invasive eye movement recording apparatus. The statistical analysis showed that saccadic latency and duration were age-dependent with the elderly displaying increased values (latency: 289±6msecs, duration: 67±3 msecs) when compared with younger observers (latency: 242±6 msecs, duration: 56±3 msecs) and middle-aged observers (latency: 256±6 msecs, duration: 50±3 msecs). No such significant effect was demonstrated for saccadic peak velocity or amplitude. Furthermore, a significant effect of gaze direction was found on all the saccadic parameters under investigation. Our results indicated no horizontal (temporal *vs.* nasal) or oblique (UN *vs.* DT and UT *vs.* DN) latency asymmetries. This result may suggest that the oculomotor system is spared from cerebral dominance. This seems to show that in humans, the performance of saccadic latencies is not related to lateral preferences (such as hand, foot, ear, eye preference) (Constantinidis, *et al.* 2003). On the other hand, a vertical latency (UP *vs.* DOWN) asymmetry was found with upward latencies being shorter than those in a downward direction. The set of muscles involved in upward gaze direction is the SR and IO whereas in the down direction is the IR and SO. Three of these muscles (SR/ IR / IO) are innervated by the oculomotor nerve whereas the SO is innervated by the trochlear nerve. Due to the fact that this asymmetry was not found in either the DN (SO muscle involved) or the DT (IR muscle involved), this asymmetry could not be attributed to differences in innervation (oculomotor versus trochlear).

In addition, horizontal (TEM *vs.* NAS) and oblique (UT *vs.* DN) asymmetries were encountered with observers having higher peak velocities in the temporal and UT directions when compared to the nasal and DN directions respectively. This result may be attributed to a possible mismatch in the corresponding discharge rates between the muscles involved (Porter, *et al.* 1995). In addition, the asymmetry in the horizontal and the oblique directions may be also explained due to innervation (i.e. abducen versus oculomotor nerve for saccadic measurements in the horizontal directions and trochlear versus oculomotor nerve for those in the oblique directions). No such asymmetry was found for the peak velocities between the vertical directions (UP *vs.* DOWN) and the other pair of oblique (UN *vs.*. DT) directions.

Observers demonstrated asymmetries on saccadic amplitudes in both pairs of oblique directions with a consistent undershoot in those directions with a downward component. This result can be explained by the fact that usually people tend to move their heads rather than their eyes when looking nasally or temporally down. The effect of gaze direction on saccadic duration indicated that observers needed longer durations to accomplish saccadic eye movements with an upward component (UP, UN, UT) when compared to those with a downward component. One possible explanation is that the population of neurons responsible for the generation of saccades in a particular direction might have a directional prevalence or bias. Alternatively, the way the muscles are innervated (oculomotor versus trochlear nerve) might form the basis of this asymmetry.

Chapter six assessed the effect of viewing distance on the metrics of saccadic eye movements. A compact device would provide an advantage in clinical settings with limited space. The results of this study indicated a non-significant effect of viewing distance (300 cm *vs.* 49 cm) on all saccadic parameters. However, significant interaction effects were found between the two viewing distances for amplitude and duration in the vertical and one pair of oblique directions. These findings may suggest that a compact version of the eye tracker and the recording system could be used, but it may be necessary to consider the possibility of different performance in particular directions (vertical and UN / DT) when the viewing distance is changed.

Chapters seven and eight investigated several factors that may commonly be encountered in a clinical environment, such as refractive defocus and cataract. The results obtained in Chapter seven indicated that there is no effect of defocus on the dynamics of saccades within a certain range (+1.00DS dioptric blur), but changes in saccadic peak velocity and duration values are introduced when a higher level of defocus (+3.00DS dioptric blur) is used. Therefore, one needs to establish an accurate refractive correction when measuring specific saccadic parameters for patients with moderate to high refractive errors.

Chapter eight investigated the effect of a cataract simulation on the parameters of saccadic eye movements. The results of this study demonstrated that simulated dense cataract led to longer latencies and durations, although no such effect was observed on saccadic peak velocity and amplitude. The findings reported in Chapter seven seem to conflict with those reported in Chapter eight for saccadic latency. Namely, our results show that the presence of dense cataract introduces changes (increase) in the measurements of latency. However, defocus, which is also known to reduce retinal contrast, did not significantly affect latency. This discrepancy suggests that reduced high spatial frequency contrast loss (due to dense cataracts) has a greater impact on latency than reduced high contrast visual acuity (due to refractive blur). In addition, both of these Chapters suggest that saccadic duration is significantly affected by both defocus and cataract simulation. This result demonstrates that this particular saccadic parameter (duration) should not be used as a diagnostic and/or monitoring tool, when significant amounts of uncorrected refractive error and/or lenticular opacities are present.

Chapter nine evaluated the application of this non-invasive eye movement methodology by investigating its capability to distinguish between normal and abnormal (amblyopic) responses. The results of this study indicated that our technique identified abnormal responses on several saccadic parameters in amblyopic observers. A direct relationship between increased saccadic latency and severity of amblyopia that had been previously reported, was confirmed. Due to lack of homogeneity within our amblyopic group, no other consistent pattern was found between amblyopes and an age-matched control group. The results of this study also verified the limited suitability of saccadic peak velocity as an investigative parameter due to its wide inter-individual variation in normals, as previously shown in Chapter four.

10.1 SUMMARY AND CONCLUSIONS

In conclusion, the results of this thesis demonstrate that this eye movement recording technique has many desirable elements that make it a useful clinical tool. Firstly, it is easy to use and gives valid and repeatable measures of several saccadic parameters in a short time. In addition, it is inexpensive and relatively comfortable for the patient to wear. However, prior to a clinical use several factors should be considered. Firstly, a substantial normative data set across a wide age range, should be recorded since age is an important physiological variable. Secondly, an accurate refractive correction should be employed in order to verify that changes in the dynamics of saccades are due to motor factors rather than an out of focus retinal image. Thirdly, the presence of dense cataracts will adversely affect the measurement of several saccadic parameters, and caution is urged in this situation.

Overall, these data sets indicated that the saccadic parameter that may provide the most effective clinical test for neurologic (e.g. multiple sclerosis, visual hemineglect, Parkinson's disease etc.) and psychiatric disorders (e.g. schizophrenia, obsessive-compulsive disorders, etc.) across different age groups is saccadic latency. This result agrees with the study of Van Dongen, *et al.* (1991). Depending on the age group under investigation, other saccadic parameters such as amplitude and duration could also be informative in disorders that affect the oculomotor system (such as Myasthenia Gravis, acute demyelinated neuropathy and Graves' ophthalmopathy etc.). The clinical suitability of peak velocity is rather less impressive due to the increased level of measurement variation between subjects in a normal population.

Further work could be carried out at different eccentricities, as well as using different tasks (i.e. antisaccade, pro-gap etc.) across a wide age range. Ideally this would enable the clinician to decide on the appropriate methodology to monitor and diagnose several diseases with extraocular muscles manifestations or involvement. In addition, a more detailed and systematic investigation of different types and degrees of real lenticular opacity should be carried out. The results would then provide clinicians with more quantifiable information on the effect of cataract on saccadic eye movement dynamics.

Another parameter that could provide useful information is the conjugacy of saccadic eye movements. This could be valuable on studies dealing with learning difficulties in reading and dyslexia. Additional work is also required in groups of patients with ocular disease, such as Graves' disease, in order to establish the most affected saccadic parameters. This would greatly facilitate our clinical ability to quantify the severity of the disease and perhaps allow us to monitor the therapeutic efficacy of any treatment protocols.

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APPENDIX A

Refereed conference abstracts

Kavasakali, M., Bloj, M. and Winn, B. (2002). Oblique saccades in visually normal human observers. *Ophthalmic and Physiological Optics,* **22** (6), 580.

APPENDIX for Chapter 4

This appendix includes the detailed individual measurements (all ten initial runs) for all observers and saccadic parameters (latency, peak velocity, amplitude, duration) in different age groups (age ranged from 20-39 years, 40-59 years and 60-89 years) and directions of gaze (TEM, NAS, UP, DOWN, UN, DT, UT, and DN). Some data points were disregarded due to the effect of anticipation (negative latencies) and/or contamination from blinks. These values appear as missing data (////). At the bottom of each column there is the average and standard deviation from all observers in that specific run. From these individual values, the averages and errors of measurements were calculated for the analysis used as described in detail in Chapter 4 in order to establish the minimum number of running averages required for establishing a representative saccadic eye movement measurement.

APPENDIX for CHAPTER 4: Establishing the min number of saccadic eye movements required for a representative result

LATENCY (msecs) 20-39 years

TEM

Number of individual runs

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	352	215	171	200	235	254	235	181	176	191
AR	244	249	230	264	176	225	230	210	220	200
AB	269	225	269	230	249	284	264	205	205	220
AN	216	212	204	230	202	214	238	276	234	266
AM	254	205	200	235	215	171	215	181	215	288
CH	235	205	200	147	83	235	186	210	210	156
DC	254	235	220	205	200	215	254	181	215	186
EP	489	254	279	225	401	259	279	235	288	210
EL	288	264	308	303	254	205	254	269	235	288
EG	308	347	323	////	323	269	259	279	264	////
IM	254	235	161	205	269	186	230	210	210	196
IU	230	186	176	210	186	181	166	176	240	210
KH	269	264	235	288	274	357	254	279	298	259
MB	230	161	215	147	220	225	240	210	191	176
MM	284	259	264	235	230	230	269	235	235	220
PM	200	171	196	191	274	249	176	205	181	210
PK	205	205	215	162	240	////	205	205	////	////
RS	274	249	230	205	240	240	337	430	249	225
SN	210	244	244	196	176	191	230	303	181	240
VA	318	244	249	249	254	523	215	230	220	196
AVG	**269**	**232**	**229**	**217**	**235**	**248**	**237**	**235**	**225**	**219**
STDEV	**65**	**40**	**43**	**42**	**63**	**79**	**39**	**59**	**34**	**37**

UP

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	////	240	205	210	171	230	210	147	88	166
AR	347	264	215	323	279	254	269	235	254	230
AB	284	249	254	215	259	259	254	259	225	254
AN	198	278	200	304	302	218	266	228	232	242
AM	////	215	215	186	210	220	200	225	210	225
CH	254	264	244	220	225	////	200	196	205	220
DC	254	205	215	215	225	215	230	235	235	240
EP	357	342	264	244	225	220	240	293	249	220
EL	479	225	215	200	342	249	269	254	254	284
EG	323	254	235	254	318	264	244	308	240	284
IM	259	230	225	220	225	220	196	235	188	215
IU	244	225	230	230	210	264	230	196	220	215
KH	284	357	254	230	225	274	284	372	225	220
MB	225	249	215	230	254	293	191	210	205	230
MM	367	298	254	264	230	244	200	254	230	274
PM	328	254	284	288	264	279	200	225	210	381
PK	293	279	191	240	196	205	210	215	240	191
RS	367	215	328	200	249	220	235	220	240	////
SN	249	244	313	244	171	191	240	200	181	220
VA	235	225	230	220	196	215	186	230	244	196
AVG	**297**	**256**	**239**	**237**	**239**	**239**	**228**	**237**	**219**	**237**
STDEV	**69**	**40**	**36**	**35**	**46**	**28**	**30**	**47**	**37**	**46**

NAS

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	215	186	191	200	181	205	156	191	171	171
AR	215	244	215	249	210	220	220	220	215	210
AB	225	249	220	249	210	215	205	186	249	186
AN	196	262	216	194	220	222	222	284	218	284
AM	230	254	196	176	142	200	210	200	205	200
CH	196	200	205	196	196	205	200	200	264	210
DC	254	235	196	215	215	220	240	249	200	235
EP	430	279	279	259	264	269	298	254	293	293
EL	230	323	230	225	210	210	181	254	205	205
EG	284	////	328	249	264	342	279	284	264	240
IM	225	186	235	220	313	293	240	186	240	215
IU	200	200	215	171	181	196	210	298	186	186
KH	274	240	225	259	249	244	244	240	259	235
MB	191	166	156	161	181	171	298	235	240	215
MM	279	259	254	235	298	313	274	240	220	450
PM	161	220	205	191	205	200	220	210	284	220
PK	181	186	210	235	191	215	161	176	200	186
RS	244	288	337	191	347	323	235	264	406	240
SN	191	171	186	176	////	200	230	200	186	293
VA	264	210	186	225	196	230	244	264	176	279
AVG	**234**	**229**	**224**	**214**	**225**	**235**	**228**	**232**	**234**	**238**
STDEV	**57**	**43**	**45**	**31**	**52**	**48**	**39**	**37**	**54**	**62**

DOWN

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	225	249	220	205	205	196	191	220	264	////
AR	////	215	215	225	196	210	215	205	205	191
AB	215	235	235	249	293	254	240	264	////	////
AN	256	190	222	246	250	250	268	314	280	278
AM	230	244	230	284	220	225	229	220	191	259
CH	264	249	230	284	249	235	220	298	210	240
DC	469	225	215	225	249	240	293	235	240	254
EP	269	284	415	254	274	259	215	240	303	264
EL	274	293	415	254	269	284	318	303	332	337
EG	376	274	274	259	313	293	303	279	288	244
IM	244	235	205	264	254	215	220	264	244	279
IU	210	240	313	244	249	288	215	264	342	235
KH	269	254	308	244	249	215	235	293	274	249
MB	284	235	264	200	244	230	225	352	////	////
MM	367	479	303	249	264	288	332	293	244	362
PM	328	269	298	254	220	391	303	279	235	298
PK	210	196	206	220	196	259	////	210	200	264
RS	////	298	244	259	259	220	215	210	235	259
SN	235	191	200	244	396	230	240	186	230	171
VA	230	249	191	274	254	200	205	210	235	196
AVG	**275**	**255**	**260**	**247**	**255**	**249**	**246**	**257**	**253**	**258**
STDEV	**69**	**61**	**65**	**23**	**44**	**45**	**43**	**45**	**43**	**48**

UN

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	347	166	235	186	196	186	200	176	////	////
AR	313	249	274	230	220	240	235	205	230	240
AB	352	240	220	259	210	269	249	337	230	200
AN	320	218	182	192	242	206	290	242	264	266
AM	489	293	259	235	357	220	318	279	////	////
CH	288	318	191	176	235	171	196	200	196	225
DC	244	240	230	225	230	225	186	240	215	254
EP	293	264	391	235	254	259	244	362	254	264
EL	254	284	181	215	200	220	210	210	264	308
EG	328	323	274	274	284	288	352	445	298	288
IM	288	269	235	196	205	200	225	196	196	205
IU	274	196	205	249	200	196	191	191	200	////
KH	318	254	313	249	240	259	264	230	244	259
MB	328	225	225	225	200	186	191	191	////	200
MM	367	240	279	240	240	181	191	259	////	////
PM	293	249	200	220	254	244	210	186	220	215
PK	210	220	274	279	205	244	200	318	308	274
RS	254	298	196	235	225	200	176	215	210	186
SN	220	196	200	191	225	191	200	181	181	191
VA	274	332	230	215	181	196	249	210	357	////
AVG	**303**	**254**	**240**	**226**	**230**	**219**	**229**	**244**	**242**	**238**
STDEV	**61**	**45**	**51**	**28**	**39**	**33**	**47**	**71**	**48**	**38**

UT

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	303	274	235	240	186	205	186	161	181	191
AR	244	284	240	259	249	230	249	196	274	240
AB	254	249	279	259	240	220	225	264	205	244
AN	206	212	228	222	236	222	244	254	278	244
AM	347	191	210	171	220	205	220	205	210	200
CH	303	274	254	240	200	244	225	186	220	210
DC	244	240	249	259	254	220	235	220	210	220
EP	303	244	386	249	274	235	288	205	220	235
EL	323	191	240	240	230	264	225	230	240	191
EG	298	240	264	293	259	220	225	284	254	235
IM	293	264	210	196	191	235	191	220	181	215
IU	264	196	196	196	220	196	205	191	176	200
KH	235	264	269	259	254	269	230	215	////	240
MB	249	220	191	191	225	210	244	205	264	181
MM	406	230	220	235	284	240	259	240	308	230
PM	288	254	225	215	215	220	244	235	220	////
PK	293	230	240	264	279	240	210	186	225	288
RS	420	225	////	254	303	244	225	225	435	459
SN	215	230	181	230	215	220	205	308	240	////
VA	264	293	215	220	191	259	////	205	181	274
AVG	**288**	**240**	**238**	**234**	**236**	**230**	**228**	**222**	**238**	**239**
STDEV	**56**	**30**	**44**	**30**	**33**	**20**	**24**	**35**	**60**	**62**

DT

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	308	205	210	240	230	230	225	220	215	230
AR	215	196	235	215	196	210	200	205	225	210
AB	323	240	215	210	230	240	279	264	264	269
AN	210	166	240	224	232	194	268	242	272	254
AM	264	205	308	230	298	249	284	269	205	274
CH	288	215	215	210	215	210	225	249	191	215
DC	215	274	284	244	279	269	274	24	259	////
EP	254	210	230	230	308	210	225	288	254	244
EL	308	230	357	294	220	200	225	244	205	210
EG	573	357	362	337	342	342	332	342	342	357
IM	200	191	200	235	230	210	186	191	191	259
IU	215	230	200	220	240	220	225	220	230	196
KH	279	313	254	308	279	293	259	269	259	284
MB	191	215	235	230	205	205	264	171	196	191
MM	386	279	244	240	284	235	259	274	347	////
PM	240	323	284	279	293	205	205	264	279	225
PK	284	210	205	259	196	210	220	196	200	////
RS	////	274	235	244	318	274	337	259	274	411
SN	225	230	244	225	420	210	240	200	196	220
VA	357	264	303	332	303	235	235	249	230	240
AVG	**281**	**241**	**253**	**250**	**266**	**233**	**248**	**232**	**242**	**252**
STDEV	**89**	**49**	**48**	**39**	**57**	**37**	**40**	**63**	**46**	**57**

DN

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	171	220	200	225	210	235	186	210	191	200
AR	230	225	205	210	220	225	220	205	225	235
AB	235	279	220	230	235	244	225	230	332	240
AN	300	264	236	254	250	218	262	270	256	264
AM	244	230	254	264	235	259	240	240	220	215
CH	269	274	244	215	240	259	210	249	264	230
DC	235	259	244	249	240	235	235	230	220	220
EP	249	244	264	293	288	240	274	254	274	288
EL	249	215	244	318	288	220	235	220	230	210
EG	415	313	298	337	288	244	308	279	313	259
IM	200	205	200	196	200	215	210	191	210	200
IU	235	332	240	235	240	200	357	264	235	////
KH	284	////	215	308	230	240	235	235	244	249
MB	205	////	191	191	156	166	152	235	254	249
MM	279	298	293	313	191	293	191	244	225	274
PM	222	226	234	228	216	248	240	222	232	246
PK	230	337	176	176	196	196	200	235	186	196
RS	411	235	264	240	284	303	264	230	249	210
SN	////	298	244	210	254	////	////	220	205	191
VA	240	235	230	215	181	205	181	171	171	142
AVG	**258**	**260**	**235**	**245**	**232**	**234**	**233**	**232**	**237**	**227**
STDEV	**62**	**41**	**32**	**46**	**37**	**32**	**47**	**26**	**39**	**35**

APPENDIX for CHAPTER 4: Establishing the min number of saccadic eye movements required for a representative result

PEAK VELOCITY (Deg/sec) 20-39 years

TEM Number of individual runs

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	548	616	548	548	514	582	616	582	514	548
AR	297	297	297	274	297	274	297	274	297	274
AB	622	674	639	622	604	656	604	587	604	587
AN	509	565	537	570	542	532	504	482	460	491
AM	478	498	518	478	498	458	458	458	478	538
CH	304	337	388	287	320	320	304	287	337	320
DC	574	556	556	556	556	574	592	556	592	538
EP	374	402	431	402	345	374	460	374	345	402
EL	556	334	534	534	556	467	512	378	556	489
EG	187	187	187	////	187	211	211	187	211	////
IM	349	349	284	349	327	327	305	349	305	327
IU	650	634	587	618	634	634	666	587	587	539
KH	500	477	454	363	250	341	386	545	477	454
MB	314	285	342	285	342	371	314	342	342	342
MM	289	231	203	260	231	231	203	289	260	145
PM	612	648	720	540	540	504	468	576	648	576
PK	204	256	204	153	204	////	230	153	////	////
RS	440	500	500	480	540	480	520	500	340	480
SN	206	206	206	206	177	177	177	147	177	177
VA	268	234	268	234	234	217	201	217	201	234
AVG	414	414	420	408	395	407	401	394	407	415
STDEV	152	163	163	151	157	150	158	154	150	142

NAS

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	261	261	285	238	261	261	238	261	261	238
AR	267	267	267	289	244	267	289	289	267	311
AB	270	337	337	337	337	337	360	315	315	360
AN	450	500	510	515	589	510	465	475	460	495
AM	286	302	286	286	286	286	270	302	270	302
CH	417	447	417	417	387	387	387	417	417	447
DC	288	220	203	237	220	220	220	220	220	271
EP	246	295	246	271	295	246	222	222	222	246
EL	451	395	282	338	338	338	395	366	338	366
EG	324	////	324	324	324	365	243	324	324	324
IM	245	184	204	143	122	163	225	204	184	163
IU	302	282	282	282	302	322	262	302	322	342
KH	338	313	289	313	265	289	289	289	265	313
MB	361	433	397	433	397	433	433	433	470	433
MM	248	248	217	248	217	248	248	248	155	279
PM	324	324	324	324	288	288	324	288	324	288
PK	343	343	343	305	343	343	305	305	343	305
RS	397	430	397	447	397	414	380	347	347	314
SN	277	333	277	333	////	333	333	333	333	333
VA	364	390	338	312	338	312	390	364	364	312
AVG	323	332	311	320	313	318	314	315	310	322
STDEV	66	83	76	84	96	80	75	71	83	75

UP

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	////	212	212	212	197	227	197	227	136	212
AR	171	214	192	171	256	192	235	214	192	192
AB	340	457	375	422	363	410	410	363	340	387
AN	316	321	362	280	425	342	398	295	335	357
AM	////	193	228	210	210	193	210	193	228	254
CH	315	236	354	334	354	////	295	295	295	315
DC	370	383	397	342	315	329	329	356	315	342
EP	125	125	125	160	143	160	160	178	143	160
EL	407	378	349	189	320	364	233	378	306	364
EG	320	353	336	336	320	320	353	370	353	336
IM	179	190	190	190	169	158	211	169	190	190
IU	194	263	251	228	217	205	228	240	217	205
KH	370	313	280	346	346	330	379	330	313	313
MB	235	201	201	251	218	201	218	251	251	201
MM	347	433	462	433	462	462	491	491	433	376
PM	161	161	184	184	184	161	161	161	138	184
PK	319	285	302	319	302	285	252	268	268	235
RS	215	215	215	215	195	195	195	195	156	////
SN	285	263	329	263	263	263	285	263	285	263
VA	248	276	276	276	276	304	276	304	304	304
AVG	273	274	281	268	277	269	276	277	260	273
STDEV	84	91	88	81	87	90	91	86	83	75

DOWN

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	258	301	258	344	301	279	365	322	365	////
AR	////	247	218	233	218	218	218	204	247	233
AB	269	269	269	296	242	296	269	242	////	////
AN	204	191	170	248	204	265	200	248	218	291
AM	255	184	241	269	255	227	227	241	170	199
CH	417	417	417	417	353	289	321	417	385	385
DC	356	370	342	327	299	299	256	327	285	256
EP	394	373	436	436	373	477	373	394	436	415
EL	267	187	241	201	214	254	201	187	187	241
EG	334	223	195	195	250	223	250	223	223	278
IM	342	327	342	264	264	249	233	187	264	311
IU	401	337	305	305	272	337	337	272	272	385
KH	343	343	320	332	332	343	309	240	286	389
MB	311	292	311	365	384	329	347	329	////	////
MM	235	305	258	235	305	328	258	235	211	211
PM	250	250	236	250	236	222	250	263	305	333
PK	293	256	201	238	256	201	////	274	219	219
RS	////	297	258	207	245	297	271	245	271	297
SN	269	269	195	269	269	195	220	220	220	244
VA	354	401	354	401	449	378	354	331	378	425
AVG	308	292	278	291	286	285	277	270	275	301
STDEV	62	69	73	72	64	69	58	64	74	75

UN

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	296	222	259	241	259	259	278	278	////	////
AR	303	280	256	350	280	256	303	326	256	256
AB	208	234	156	156	130	208	208	182	208	208
AN	407	510	440	412	458	445	374	412	425	407
AM	125	125	179	161	143	143	161	143	////	////
CH	369	431	461	461	431	431	461	461	431	431
DC	368	368	368	368	338	338	307	307	307	338
EP	291	249	249	311	249	291	270	228	228	249
EL	376	399	376	329	376	352	258	305	305	329
EG	259	311	311	285	259	259	259	285	285	285
IM	262	262	262	224	224	243	224	243	206	206
IU	149	174	249	224	199	249	199	199	249	////
KH	516	516	473	473	516	516	559	559	473	559
MB	320	256	320	256	256	256	256	256	////	256
MM	270	243	243	270	297	297	270	243	////	////
PM	170	186	186	155	217	170	201	186	186	170
PK	231	231	264	264	198	264	198	231	297	264
RS	378	413	378	344	395	361	361	378	344	327
SN	356	328	328	328	328	274	274	301	328	328
VA	220	220	183	183	147	220	220	183	183	////
AVG	**294**	**298**	**297**	**290**	**285**	**292**	**282**	**285**	**294**	**308**
STDEV	**96**	**109**	**95**	**95**	**108**	**92**	**96**	**103**	**89**	**100**

UT

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	415	415	415	475	445	445	505	415	385	445
AR	269	245	220	245	220	269	220	245	220	245
AB	295	311	295	295	344	344	360	327	327	311
AN	390	390	349	366	415	482	382	499	465	357
AM	305	237	254	254	254	271	254	237	271	271
CH	377	434	471	377	377	396	434	358	339	245
DC	562	581	600	562	581	581	562	544	581	562
EP	334	367	400	334	367	367	367	334	367	367
EL	452	472	411	411	431	493	452	411	493	329
EG	373	404	389	373	389	435	373	373	389	373
IM	367	387	290	309	309	367	348	309	348	232
IU	298	340	298	404	276	276	255	319	319	298
KH	361	321	301	401	341	361	281	261	////	321
MB	383	434	459	383	383	383	332	383	408	434
MM	358	310	293	261	261	196	228	261	277	212
PM	331	331	199	265	265	331	331	265	265	////
PK	321	406	364	385	364	321	385	321	321	342
RS	187	250	////	297	297	281	172	297	219	265
SN	277	297	297	258	297	258	258	258	258	////
VA	261	302	362	342	342	342	////	281	342	261
AVG	**346**	**362**	**351**	**350**	**348**	**360**	**342**	**335**	**347**	**326**
STDEV	**79**	**85**	**97**	**81**	**83**	**94**	**101**	**83**	**93**	**89**

DT

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	336	336	301	389	301	301	265	263	318	372
AR	319	297	319	297	319	297	297	319	276	297
AB	398	398	367	398	337	245	230	260	276	260
AN	573	476	401	470	487	413	482	505	528	503
AM	286	428	303	321	500	411	482	482	428	428
CH	355	290	323	258	371	323	355	306	306	323
DC	338	271	248	248	248	271	271	293	293	////
EP	279	384	314	314	244	279	279	279	244	314
EL	416	307	329	373	329	307	373	329	329	351
EG	319	346	293	266	319	346	266	373	346	346
IM	257	273	289	305	289	177	241	305	241	225
IU	302	483	402	443	423	402	342	302	322	402
KH	273	228	273	228	273	273	273	182	228	273
MB	397	397	364	430	430	397	331	397	364	364
MM	289	209	257	193	160	160	257	193	305	////
PM	352	369	318	369	352	285	285	302	184	184
PK	375	333	417	229	438	438	292	354	313	////
RS	////	409	370	350	195	175	350	234	409	448
SN	297	233	254	233	233	212	212	212	191	191
VA	214	232	285	268	214	232	214	214	250	285
AVG	**336**	**335**	**321**	**319**	**323**	**297**	**305**	**305**	**308**	**327**
STDEV	**78**	**82**	**51**	**80**	**96**	**84**	**76**	**86**	**82**	**88**

DN

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	305	348	348	392	348	348	305	436	436	392
AR	295	268	295	268	241	268	348	295	268	268
AB	206	240	206	240	240	240	206	189	206	189
AN	316	236	251	181	285	206	266	316	306	271
AM	194	158	194	176	141	158	176	158	123	123
CH	401	401	449	425	378	401	401	425	378	354
DC	397	303	378	359	284	359	321	321	303	303
EP	423	352	317	282	317	317	211	282	282	247
EL	430	391	410	410	430	527	488	273	332	371
EG	231	259	231	288	202	259	231	202	173	231
IM	284	248	213	230	248	195	230	248	213	230
IU	330	330	391	330	288	288	350	412	412	////
KH	258	////	235	282	305	305	258	258	211	258
MB	333	////	363	333	333	394	333	394	303	394
MM	280	233	256	163	256	349	256	303	233	163
PM	212	232	212	232	172	212	159	172	205	192
PK	311	384	366	366	329	348	293	384	366	311
RS	231	277	293	293	247	277	308	308	308	308
SN	////	391	391	391	335	////	////	363	363	363
VA	323	416	416	393	347	347	347	370	323	370
AVG	**303**	**304**	**311**	**302**	**286**	**305**	**289**	**305**	**287**	**281**
STDEV	**72**	**75**	**82**	**82**	**70**	**88**	**81**	**84**	**83**	**81**

APPENDIX for CHAPTER 4: Establishing the min number of saccadic eye movements required for a representative result

AMPLITUDE (Degrees) 20-39 years

TEM

Number of individual runs

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	14.05	13.55	12.54	12.88	13.55	14.88	14.21	14.21	13.71	13.88
AR	9.03	8.70	8.25	9.48	8.70	9.81	9.14	8.36	8.92	9.48
AB	12.82	13.07	13.32	12.73	12.40	12.99	12.90	12.90	12.31	11.98
AN	9.89	11.49	10.54	11.45	11.02	10.61	9.69	10.44	10.34	9.81
AM	13.61	12.84	13.81	10.02	12.74	12.25	12.55	11.96	12.74	14.00
CH	7.90	8.48	9.39	8.15	8.15	8.65	8.73	9.22	8.73	8.65
DC	13.06	12.88	12.88	12.62	12.27	12.71	12.79	12.97	13.14	12.44
EP	9.96	11.22	10.52	11.22	9.68	10.10	10.52	9.68	9.82	10.66
EL	11.84	11.62	11.19	12.16	11.95	10.97	12.38	11.51	12.49	10.86
EG	6.29	6.29	8.00	////	7.43	9.03	9.26	7.89	7.77	////
IM	9.90	10.65	8.52	10.12	11.18	10.01	9.69	9.37	8.73	10.12
IU	12.62	11.38	11.77	11.69	11.61	11.85	12.16	11.00	9.45	10.14
KH	11.53	11.42	10.31	9.20	8.43	9.43	10.53	11.98	11.53	10.76
MB	7.80	6.69	8.08	5.57	7.94	7.94	7.66	7.80	7.66	7.66
MM	7.91	8.76	10.17	7.06	7.49	7.49	7.91	8.48	7.06	7.63
PM	11.60	12.30	11.95	11.77	11.77	12.13	11.77	12.13	11.25	11.95
PK	6.74	6.24	7.49	4.12	6.61	////	6.36	5.74	////	////
RS	9.67	10.94	10.74	11.82	11.43	10.84	12.01	11.03	10.45	9.96
SN	5.90	5.61	5.90	5.47	5.47	4.89	4.61	4.46	4.61	5.04
VA	5.88	5.47	7.19	6.12	5.80	5.39	5.47	5.72	6.12	6.53
AVG	**9.90**	**9.98**	**10.13**	**9.67**	**9.78**	**10.10**	**10.02**	**9.84**	**9.83**	**10.09**
STDEV	**2.66**	**2.71**	**2.22**	**2.80**	**2.50**	**2.54**	**2.66**	**2.65**	**2.52**	**2.38**

NAS

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	7.19	9.75	7.77	7.54	9.40	8.47	8.70	7.19	8.47	7.43
AR	8.57	8.79	8.57	9.55	8.03	9.01	8.03	9.01	9.01	9.44
AB	7.79	9.11	10.10	9.66	9.22	9.55	10.32	8.67	9.44	9.88
AN	11.08	11.70	12.27	11.62	11.79	11.54	10.54	10.52	10.92	11.27
AM	8.39	9.16	7.46	8.39	8.00	7.69	7.53	9.40	7.69	8.08
CH	10.33	10.77	11.06	10.77	10.19	11.06	10.33	10.62	11.35	11.79
DC	8.76	8.43	7.44	7.85	7.69	8.43	8.27	8.52	7.94	8.93
EP	7.09	7.81	6.37	6.37	6.73	6.13	5.77	5.77	5.53	6.73
EL	10.19	9.22	10.05	10.05	8.67	9.50	9.77	8.67	9.50	8.67
EG	12.87	////	13.06	13.46	12.27	14.45	13.06	13.86	13.06	14.05
IM	7.38	6.08	6.78	4.49	4.88	6.18	6.78	6.78	5.78	5.38
IU	8.06	7.27	8.26	6.88	7.47	7.18	7.67	8.65	8.45	8.45
KH	9.30	8.36	8.36	8.59	7.65	8.59	8.12	8.24	9.30	9.30
MB	9.52	10.41	9.70	11.46	11.29	10.76	10.58	11.11	12.35	11.64
MM	9.97	9.52	8.46	8.77	8.61	9.67	8.77	7.25	7.56	9.37
PM	8.43	8.08	8.96	8.79	8.96	8.96	9.66	8.61	8.61	7.56
PK	10.05	10.61	10.61	10.05	9.68	10.61	10.42	10.24	10.42	10.24
RS	11.71	12.04	10.90	12.36	11.23	11.79	10.90	10.58	10.74	9.69
SN	8.94	10.30	9.48	10.30	////	10.57	10.30	10.57	10.84	10.30
VA	9.40	11.82	9.78	9.02	9.78	8.64	11.94	9.66	10.92	9.28
AVG	**9.25**	**9.43**	**9.27**	**9.30**	**9.03**	**9.44**	**9.37**	**9.20**	**9.39**	**9.37**
STDEV	**1.52**	**1.59**	**1.77**	**2.13**	**1.85**	**2.00**	**1.79**	**1.81**	**1.98**	**1.94**

UP

Sbjs	1	2	3	4	5	6	7	8	9	10
AS		8.34	8.05	7.16	7.60	8.64	7.46	7.83	6.64	7.09
AR	7.72	10.84	8.97	9.28	8.76	9.38	9.70	9.49	10.32	11.99
AB	9.04	9.27	8.53	9.33	9.84	9.19	8.87	8.58	8.13	9.56
AN	9.60	9.32	9.34	8.85	10.54	9.03	8.47	9.48	9.09	8.93
AM	////	8.65	8.99	8.73	8.90	8.22	8.30	9.33	9.76	10.36
CH	8.64	6.24	8.83	9.50	9.98	////	8.45	8.26	8.35	8.74
DC	9.76	9.63	8.96	9.16	9.83	9.03	9.09	8.22	8.02	9.09
EP	6.62	5.75	6.70	8.10	7.49	7.83	7.14	8.10	8.36	8.71
EL	10.02	10.09	10.37	9.87	8.88	8.31	9.38	8.45	8.95	9.45
EG	7.72	9.28	9.03	9.44	9.61	9.61	9.03	9.36	9.03	9.20
IM	9.89	8.80	9.47	8.70	8.55	8.29	8.44	8.55	7.93	8.91
IU	7.75	9.53	9.14	8.75	8.75	7.36	8.75	8.08	8.03	7.86
KH	10.30	11.99	11.43	12.47	12.87	12.31	13.60	12.15	14.40	12.87
MB	6.69	4.75	4.58	5.81	5.89	5.65	5.48	6.30	5.24	4.91
MM	10.86	11.15	10.72	11.29	12.84	11.85	11.99	14.53	10.02	10.02
PM	6.64	3.71	4.61	7.77	6.42	5.18	4.50	5.85	4.84	6.87
PK	8.85	9.17	9.42	8.68	9.26	8.68	8.03	8.60	8.27	8.52
RS	7.82	7.62	7.24	6.67	7.15	6.58	7.91	8.58	8.39	////
SN	8.36	9.22	9.33	9.11	8.90	8.68	9.11	9.00	9.22	8.68
VA	6.47	8.09	8.62	8.22	8.09	7.82	7.01	7.41	8.76	8.89
AVG	**8.48**	**8.57**	**8.62**	**8.84**	**9.01**	**8.51**	**8.54**	**8.81**	**8.59**	**8.98**
STDEV	**1.39**	**2.09**	**1.73**	**1.46**	**1.78**	**1.73**	**1.95**	**1.86**	**1.94**	**1.73**

DOWN

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	8.81	8.91	8.18	10.59	9.86	8.28	11.11	9.23	9.65	////
AR	////	7.74	6.25	6.67	6.10	6.60	7.10	6.53	6.67	7.03
AB	7.89	8.41	8.81	8.15	9.86	8.94	8.02	9.07	////	////
AN	5.16	5.08	6.23	7.11	6.40	5.82	5.12	5.76	6.45	7.50
AM	6.93	5.47	5.26	6.37	6.58	5.82	6.58	7.20	6.37	6.58
CH	10.81	9.71	10.02	10.96	9.24	9.08	8.77	11.59	10.02	9.40
DC	9.31	10.07	9.52	9.45	8.55	8.34	8.96	10.35	9.31	10.14
EP	10.74	11.44	11.44	11.24	9.52	11.75	10.33	11.24	11.04	11.68
EL	7.25	5.88	6.60	9.34	6.73	6.14	5.49	5.03	5.49	5.68
EG	10.05	9.10	8.97	8.56	8.97	8.83	9.51	8.70	9.24	9.10
IM	9.87	10.40	10.25	11.09	9.19	9.04	7.82	8.35	9.42	9.80
IU	10.33	10.88	9.78	10.80	8.53	11.43	11.74	10.17	9.39	11.50
KH	8.15	7.70	7.20	7.48	7.65	7.93	7.99	6.53	8.10	9.49
MB	8.23	8.39	8.48	10.71	10.71	9.64	8.57	8.92	////	////
MM	6.64	7.79	7.68	6.53	8.02	8.13	6.64	7.10	6.07	6.64
PM	8.06	6.91	7.58	8.53	7.99	7.31	6.84	6.91	7.92	10.77
PK	7.86	6.79	5.80	7.50	7.50	6.07	////	8.13	7.32	7.14
RS	////	7.00	8.89	7.12	6.68	7.56	7.18	6.74	7.31	6.87
SN	8.11	9.42	7.75	8.71	9.07	9.30	7.99	8.71	7.75	8.11
VA	8.99	11.07	11.30	11.41	12.68	11.87	10.38	12.68	12.11	12.45
AVG	**9.90**	**9.98**	**10.13**	**9.67**	**9.78**	**10.10**	**10.02**	**9.84**	**9.83**	**10.09**
STDEV	**2.66**	**2.71**	**2.22**	**2.80**	**2.50**	**2.54**	**2.66**	**2.65**	**2.52**	**2.38**

UN

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	11.48	10.22	10.39	9.70	11.48	11.12	11.93	10.85	////	////
AR	8.76	8.76	8.76	10.35	8.65	9.44	7.74	9.56	7.28	8.87
AB	9.00	9.76	7.98	6.84	7.10	9.63	10.52	8.62	8.87	9.50
AN	11.99	12.53	11.61	11.79	13.73	11.64	11.64	12.28	12.40	12.32
AM	9.35	9.35	10.58	11.89	9.18	9.70	10.92	10.49	////	////
CH	11.26	13.36	13.06	12.91	12.61	12.91	12.61	13.81	13.21	13.21
DC	9.74	9.74	10.79	10.64	10.79	10.04	10.04	9.84	10.79	10.34
EP	8.31	8.01	8.01	8.62	7.20	7.91	7.60	8.21	7.50	7.50
EL	9.29	9.29	9.40	8.26	9.29	8.72	8.83	9.98	7.80	8.83
EG	9.50	10.89	10.89	11.52	10.38	11.14	9.37	11.02	11.90	11.40
IM	8.76	8.58	9.95	7.94	8.58	8.03	8.21	8.76	7.57	7.67
IU	10.09	8.87	13.97	14.70	15.68	15.07	11.79	15.80	15.80	////
KH	16.37	17.84	17.63	17.84	18.89	19.52	18.47	20.78	19.31	18.89
MB	7.51	5.94	6.25	5.63	5.94	5.63	5.63	5.63	////	5.32
MM	9.63	10.02	10.29	13.32	10.95	13.45	11.74	9.89	////	////
PM	5.22	6.58	7.63	6.65	8.31	6.12	7.86	7.03	7.33	7.71
PK	12.58	15.49	14.52	13.71	14.84	14.52	12.10	13.23	13.23	15.17
RS	11.16	11.42	10.91	11.25	11.42	11.16	11.50	11.67	10.74	11.67
SN	12.83	12.83	12.56	12.83	12.42	12.56	12.69	13.09	12.96	12.42
VA	13.61	12.18	8.95	11.10	10.39	11.46	10.56	10.92	9.85	////
AVG	**10.32**	**10.58**	**10.71**	**10.87**	**10.89**	**10.99**	**10.59**	**11.07**	**11.03**	**10.72**
STDEV	**2.44**	**2.87**	**2.68**	**3.00**	**3.18**	**3.22**	**2.71**	**3.30**	**3.43**	**3.44**

UT

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	11.16	11.88	11.45	10.87	11.88	10.72	11.45	11.59	10.29	10.87
AR	9.09	9.33	7.53	9.45	9.33	7.89	9.92	8.13	8.73	11.36
AB	7.51	8.87	8.63	9.19	9.03	9.51	10.07	8.87	10.07	8.79
AN	10.68	13.70	10.38	11.88	12.22	11.36	12.04	12.87	14.98	11.03
AM	10.74	9.92	10.83	12.07	10.25	10.99	10.91	11.73	10.83	12.07
CH	9.76	10.59	11.05	9.48	10.31	10.96	11.33	11.05	10.22	8.29
DC	11.71	12.17	12.54	13.09	13.27	12.63	13.54	11.90	12.90	12.81
EP	9.12	9.77	11.89	9.94	10.10	9.94	9.12	9.94	9.28	10.42
EL	10.13	11.74	10.23	10.83	11.03	11.74	12.14	11.13	12.54	10.13
EG	9.64	10.25	9.95	9.95	10.02	10.40	10.10	9.49	10.25	10.02
IM	11.14	11.70	7.27	11.14	10.19	10.29	11.23	10.10	11.04	10.76
IU	10.58	10.48	9.75	10.90	9.13	9.34	7.68	10.17	9.34	9.86
KH	9.39	8.51	9.59	10.67	10.28	11.16	9.79	11.06	////	11.06
MB	7.47	7.84	8.84	8.34	7.84	6.97	7.22	7.47	8.72	8.59
MM	11.22	10.74	8.99	12.25	10.26	10.26	10.42	8.27	11.14	8.35
PM	6.79	8.08	8.73	9.70	9.05	7.76	10.99	10.02	8.08	////
PK	11.49	12.74	12.11	12.53	11.90	11.07	12.11	10.44	10.86	13.05
RS	9.07	9.99	////	10.29	8.54	10.60	9.22	10.44	10.21	8.31
SN	8.90	9.29	9.48	8.52	9.58	7.94	8.13	9.00	9.19	////
VA	7.56	8.93	10.01	9.82	9.72	10.31	////	8.44	9.03	8.05
AVG	**9.66**	**10.33**	**9.96**	**10.54**	**10.20**	**10.09**	**10.39**	**10.11**	**10.41**	**10.21**
STDEV	**1.48**	**1.60**	**1.46**	**1.32**	**1.33**	**1.47**	**1.64**	**1.43**	**1.67**	**1.57**

DT

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	9.16	10.45	8.29	7.95	8.38	7.08	6.65	10.28	7.95	10.02
AR	6.84	7.88	9.12	9.23	8.09	8.50	8.40	8.40	7.47	7.67
AB	9.49	10.61	9.72	10.39	7.70	6.50	6.88	6.65	6.50	7.55
AN	11.76	10.14	9.30	10.64	11.57	8.62	10.99	10.98	10.61	10.83
AM	7.67	13.25	9.68	8.98	11.51	10.37	10.63	11.77	10.29	10.90
CH	8.27	6.61	8.43	7.01	7.87	8.58	7.95	7.40	8.50	8.03
DC	7.71	6.94	6.94	6.83	7.82	7.05	6.72	7.05	7.05	////
EP	7.33	8.19	7.33	6.82	6.82	6.48	7.50	8.53	8.36	8.36
EL	7.92	7.17	7.06	7.06	7.71	8.56	7.92	7.92	8.78	10.06
EG	8.45	9.23	8.97	8.06	10.53	9.23	8.71	9.75	11.44	11.57
IM	8.16	10.67	10.44	9.81	9.81	7.69	9.34	10.28	9.03	7.93
IU	7.27	11.10	9.63	10.90	9.33	11.99	11.10	10.12	10.22	13.46
KH	7.12	6.67	7.56	7.34	8.01	7.78	7.78	7.56	7.12	9.34
MB	7.43	8.07	9.04	8.24	9.04	8.24	9.04	8.40	7.11	7.11
MM	6.82	6.11	7.21	9.56	7.13	7.84	6.74	10.03	7.60	////
PM	9.74	9.82	8.92	9.41	8.84	6.55	6.71	7.36	4.34	4.09
PK	10.79	11.60	12.11	9.57	13.74	15.37	8.04	13.13	11.70	////
RS	////	9.98	9.69	8.84	9.03	8.08	9.31	8.17	9.79	9.98
SN	9.01	6.21	7.25	7.14	7.76	6.42	6.11	6.00	6.21	5.90
VA	4.44	5.49	6.45	5.31	4.09	5.05	4.44	4.62	4.79	4.97
AVG	**8.18**	**8.81**	**8.66**	**8.45**	**8.74**	**8.30**	**8.05**	**8.72**	**8.24**	**8.69**
STDEV	**1.61**	**2.16**	**1.41**	**1.51**	**2.04**	**2.25**	**1.71**	**2.06**	**2.03**	**2.44**

DN

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	7.23	10.64	10.64	10.00	9.36	8.51	11.49	10.21	11.27	10.64
AR	6.41	7.46	6.80	7.06	5.76	6.93	7.06	7.72	6.54	6.28
AB	5.78	6.03	5.45	5.95	6.03	5.70	5.70	5.61	5.70	5.78
AN	9.27	7.22	7.49	6.92	7.25	6.09	6.51	7.28	7.92	6.99
AM	4.90	4.56	5.42	5.67	4.47	4.90	5.42	5.16	5.07	4.73
CH	9.57	9.22	9.91	8.65	8.88	9.11	9.11	10.14	8.99	7.61
DC	9.42	9.79	9.88	9.70	9.23	9.88	9.88	9.88	9.05	9.51
EP	9.29	8.43	7.05	7.22	7.39	7.05	6.02	7.74	7.57	6.02
EL	9.82	9.25	7.92	9.44	9.54	9.73	9.44	8.97	9.44	9.73
EG	7.46	8.44	8.02	7.88	6.89	7.60	7.04	7.04	6.61	7.18
IM	8.39	8.83	7.44	6.75	8.05	6.92	8.39	7.70	6.40	7.10
IU	8.15	11.57	11.57	8.35	13.68	10.96	12.37	13.18	14.28	////
KH	5.61	////	5.73	6.53	7.45	7.56	6.42	6.53	5.84	5.73
MB	8.72	////	7.84	9.31	8.72	9.02	6.65	7.98	7.24	8.87
MM	8.30	7.62	7.62	6.26	8.30	9.78	8.87	7.74	9.33	7.96
PM	5.42	7.63	6.79	8.45	6.30	6.74	6.37	5.06	6.13	7.12
PK	9.21	7.96	9.56	10.99	10.28	10.28	7.42	13.23	9.03	9.56
RS	6.62	8.35	7.98	9.11	8.88	8.35	8.58	8.96	10.39	8.81
SN	////	9.95	10.36	9.95	10.09	////	////	10.09	9.14	9.95
VA	8.46	10.83	10.38	9.93	9.25	9.70	9.70	10.72	9.25	10.15
AVG	**7.79**	**8.54**	**8.19**	**8.21**	**8.29**	**8.15**	**8.02**	**8.55**	**8.26**	**7.88**
STDEV	**1.58**	**1.72**	**1.82**	**1.58**	**2.00**	**1.71**	**1.97**	**2.31**	**2.22**	**1.75**

APPENDIX for CHAPTER 4: Establishing the min number of saccadic eye movements required for a representative result

DURATION (msecs) 20-39 years

TEM

Number of individual runs

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	49	49	59	34	39	34	54	34	34	54
AR	64	59	64	54	44	49	59	54	44	68
AB	39	39	39	39	39	39	39	44	39	49
AN	32	38	32	34	34	38	32	38	34	30
AM	44	59	44	39	39	54	39	39	44	54
CH	44	49	49	44	44	49	49	59	44	49
DC	44	44	44	44	44	44	44	49	44	44
EP	44	49	54	39	44	44	44	44	64	54
EL	39	54	39	39	39	39	39	44	39	44
EG	59	54	93	////	64	98	108	64	54	////
IM	44	49	44	64	49	54	49	44	44	49
IU	39	34	39	39	39	39	39	39	34	39
KH	44	44	39	44	54	44	49	44	44	39
MB	39	34	34	29	39	39	39	39	44	34
MM	39	49	59	44	44	49	59	44	39	73
PM	44	44	44	54	39	44	59	44	64	39
PK	78	64	117	88	68	////	73	78	////	////
RS	39	39	39	44	39	39	44	39	59	39
SN	34	39	44	39	44	34	34	39	39	44
VA	34	34	44	34	39	34	39	39	44	39
AVG	45	46	51	44	44	45	50	46	45	47
STDEV	11	9	21	13	9	14	17	10	9	11

UP

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	////	98	83	78	103	88	88	83	103	59
AR	98	122	88	98	112	88	98	83	103	112
AB	49	39	39	49	64	44	39	44	39	49
AN	64	70	60	90	58	126	50	84	56	76
AM	////	78	68	64	73	73	68	73	68	83
CH	49	39	44	54	54	////	49	44	44	49
DC	49	49	49	54	59	59	54	49	49	54
EP	93	73	93	93	88	93	78	93	108	98
EL	49	49	59	98	64	49	78	39	59	49
EG	39	49	49	59	68	68	49	49	54	64
IM	108	88	147	103	98	103	83	93	73	142
IU	64	64	64	64	73	64	73	64	68	73
KH	59	68	73	68	78	83	78	68	83	73
MB	44	34	34	34	39	39	39	44	29	34
MM	59	49	39	39	54	44	44	59	44	44
PM	78	39	39	83	73	54	44	68	64	73
PK	44	49	54	44	54	49	49	54	49	59
RS	68	59	59	54	59	49	68	73	93	////
SN	44	54	44	49	54	54	54	54	54	49
VA	34	44	44	44	39	39	39	39	44	44
AVG	61	61	61	66	68	67	61	63	64	68
STDEV	21	23	26	22	20	24	18	18	23	27

NAS

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	44	88	49	49	93	68	78	39	49	73
AR	49	54	49	54	59	49	49	54	49	49
AB	44	44	44	44	39	44	44	44	44	39
AN	44	38	42	44	36	42	42	34	46	40
AM	59	44	54	39	59	59	54	44	39	39
CH	39	49	44	44	39	44	44	39	44	49
DC	44	59	49	49	54	59	54	54	54	49
EP	39	39	39	39	34	39	39	39	39	34
EL	49	34	54	44	49	44	39	34	49	39
EG	78	////	54	54	59	68	68	59	68	68
IM	49	59	54	44	73	64	49	49	49	54
IU	49	54	54	44	44	34	54	54	39	39
KH	44	44	49	44	39	39	44	44	49	44
MB	54	54	34	39	39	44	59	39	64	54
MM	59	64	64	54	73	64	68	54	78	59
PM	64	59	49	44	49	44	44	54	44	59
PK	39	68	44	44	49	44	54	49	54	54
RS	44	44	44	44	39	44	44	44	49	44
SN	59	54	59	54	////	49	44	49	49	54
VA	44	44	44	44	44	44	44	44	49	49
AVG	50	52	49	46	51	49	51	46	50	49
STDEV	10	13	7	5	15	10	11	7	10	10

DOWN

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	44	58	49	59	54	54	54	44	59	////
AR	////	49	44	44	44	49	49	54	49	49
AB	44	49	49	44	59	44	44	49	////	////
AN	50	60	68	60	58	40	58	52	60	46
AM	44	49	39	34	39	39	39	54	64	49
CH	49	59	49	68	54	68	54	54	54	49
DC	39	49	44	49	54	44	68	64	49	64
EP	59	44	39	54	54	39	49	44	44	44
EL	44	44	44	68	49	44	49	44	39	39
EG	59	68	64	73	68	35	64	59	59	54
IM	44	49	54	68	54	64	59	68	54	54
IU	64	49	49	49	44	49	59	54	44	44
KH	44	49	44	44	49	44	59	49	44	59
MB	44	64	49	64	59	49	39	44	////	////
MM	39	44	49	44	49	44	39	44	44	49
PM	44	44	49	49	54	49	44	44	39	49
PK	44	59	54	59	44	54	////	54	59	49
RS	////	44	64	44	44	44	44	44	49	44
SN	49	59	54	54	54	73	54	59	54	54
VA	44	44	49	49	44	49	39	64	54	54
AVG	47	52	50	54	51	49	51	52	51	50
STDEV	7	8	8	11	7	10	9	8	7	6

UN

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	83	83	78	64	88	83	93	88	////	////
AR	73	73	68	78	73	93	54	73	49	68
AB	83	88	93	68	88	88	93	83	83	88
AN	52	46	56	52	54	46	78	58	52	56
AM	122	117	112	132	98	117	117	112	////	////
CH	54	54	64	68	68	64	54	54	59	59
DC	44	49	54	54	59	49	64	54	59	49
EP	44	54	49	44	54	49	54	59	54	54
EL	39	34	39	49	39	39	59	59	39	49
EG	54	59	59	73	59	68	54	59	64	59
IM	54	54	78	59	59	49	59	73	64	59
IU	98	93	98	108	161	112	103	122	112	////
KH	83	83	103	103	88	93	98	98	83	78
MB	39	34	39	34	29	34	34	34	////	34
MM	64	68	83	112	88	103	93	83	////	////
PM	49	73	98	83	88	73	78	78	78	88
PK	112	132	103	98	142	132	112	117	103	112
RS	44	49	44	53	44	49	54	49	54	54
SN	49	64	54	64	59	68	68	68	64	59
VA	127	112	78	103	108	108	103	117	122	////
AVG	68	71	72	75	77	76	76	77	71	64
STDEV	28	27	23	26	33	29	24	25	24	20

DT

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	54	49	49	44	39	34	49	54	39	44
AR	54	59	44	49	44	49	49	44	49	49
AB	39	49	44	44	39	39	59	39	58	39
AN	38	32	36	36	40	34	38	36	36	38
AM	44	78	59	64	44	44	44	49	39	44
CH	39	34	44	39	39	49	44	39	49	49
DC	39	59	54	54	78	49	44	44	68	////
EP	44	39	39	44	54	39	44	39	44	54
EL	34	34	39	34	44	39	34	49	39	44
EG	39	39	49	39	54	44	44	44	49	54
IM	64	68	64	54	59	64	68	68	59	59
IU	34	34	39	39	34	59	44	49	49	59
KH	39	54	49	49	59	49	64	54	49	59
MB	54	59	64	73	64	59	39	59	49	54
MM	39	49	49	93	78	83	44	98	39	////
PM	44	54	49	54	49	44	49	64	39	39
PK	49	64	59	83	93	78	44	78	59	////
RS	////	44	44	39	59	88	39	49	39	39
SN	49	34	49	44	49	49	44	39	44	49
VA	34	34	34	29	24	34	34	34	29	29
AVG	44	48	48	50	52	51	46	51	46	47
STDEV	8	13	9	17	17	16	9	16	9	9

UT

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	44	49	44	49	49	49	39	64	49	44
AR	64	59	54	73	88	68	93	59	73	98
AB	39	44	44	49	44	44	49	44	54	44
AN	54	72	62	66	72	50	92	54	86	54
AM	83	78	88	98	83	83	73	88	78	88
CH	44	44	44	44	49	54	44	49	49	54
DC	39	39	44	44	49	44	44	39	44	44
EP	44	39	49	44	54	44	54	54	44	54
EL	39	49	44	49	54	44	54	44	49	49
EG	54	54	54	54	49	54	54	44	59	59
IM	49	44	44	64	54	49	64	54	54	112
IU	64	54	64	54	59	68	59	54	78	64
KH	44	49	64	59	64	59	68	83	////	59
MB	29	29	34	39	39	44	34	29	34	39
MM	64	88	54	103	83	103	88	54	93	83
PM	44	49	68	83	54	44	64	64	54	////
PK	49	59	54	54	54	59	54	59	54	59
RS	78	59	////	68	44	78	88	78	83	59
SN	49	54	54	54	59	49	49	54	54	////
VA	39	44	44	44	49	49	////	44	44	49
AVG	51	53	53	60	57	57	61	56	60	62
STDEV	14	14	12	18	14	16	18	15	17	20

DN

Sbjs	1	2	3	4	5	6	7	8	9	10
AS	39	49	54	44	54	39	68	39	49	49
AR	39	44	49	39	39	49	39	39	39	39
AB	44	34	39	39	39	34	39	44	39	49
AN	50	60	48	58	46	48	48	44	50	46
AM	39	39	44	44	39	44	44	49	64	59
CH	40	39	44	34	44	39	39	44	44	34
DC	39	49	49	44	54	44	59	59	54	49
EP	44	44	59	39	39	39	39	49	39	34
EL	39	44	34	39	34	39	34	54	59	44
EG	44	49	49	39	44	49	44	44	49	49
IM	44	59	54	49	49	49	59	54	44	54
IU	49	59	49	44	83	31	59	59	64	////
KH	34	////	39	39	39	44	39	49	39	34
MB	54	////	54	49	54	44	34	49	39	54
MM	54	49	54	68	54	49	68	44	73	78
PM	42	56	48	58	84	54	54	42	46	54
PK	44	34	49	54	68	54	39	73	49	49
RS	44	49	44	49	54	49	49	49	54	49
SN	////	49	44	44	49	////	////	49	44	49
VA	39	39	39	34	39	39	44	44	39	44
AVG	43	47	47	45	50	44	47	49	49	48
STDEV	5	8	6	9	14	6	11	8	10	10

APPENDIX for CHAPTER 4: Establishing the min number of saccadic eye movements required for a representative result

LATENCY (msecs) 40-59 years

TEM

Number of individual runs

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	426	284	260	274	290	270	276	402	348	290
CV	250	320	228	230	344	260	288	258	262	310
DT	272	210	226	242	232	244	282	260	276	274
JB	252	208	220	244	220	242	188	254	284	258
LS	244	230	235	369	230	210	205	186	220	196
SL	318	259	235	230	269	298	240	230	244	254
SA	235	215	196	210	205	166	191	181	215	166
DB	220	196	191	230	205	205	191	196	186	196
GC	240	244	181	215	205	215	205	205	215	156
JL	293	323	313	303	240	318	////	303	259	225
LK	249	288	249	152	220	215	171	240	200	////
SHE	346	////	246	294	306	262	368	298	256	282
SH	240	225	264	215	240	225	240	230	191	235
BD	396	288	205	279	225	240	259	220	240	284
DK	252	270	246	340	234	274	236	200	282	356
GB	328	244	235	220	254	225	249	171	220	210
LB	308	249	244	200	210	235	200	249	205	230
MT	264	210	220	220	200	181	215	235	191	225
SF	445	293	313	274	328	318	308	244	196	274
TK	298	244	235	215	220	205	210	249	205	220
AVG	**294**	**253**	**237**	**248**	**244**	**240**	**238**	**240**	**235**	**244**
STDEV	**65**	**39**	**34**	**51**	**42**	**41**	**50**	**52**	**42**	**50**

UP

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	328	330	234	256	258	268	250	274	336	326
CV	356	296	232	290	330	272	284	276	240	278
DT	286	316	240	246	360	250	278	280	246	302
JB	264	292	220	230	248	262	214	254	298	308
LS	293	220	210	230	205	230	186	196	220	205
SL	274	249	254	220	220	240	279	205	254	244
SA	244	225	181	176	191	171	////	191	176	205
DB	274	205	240	215	205	230	235	215	200	////
GC	230	230	235	////	215	////	210	274	279	240
JL	347	274	313	254	274	303	347	303	293	318
LK	435	313	303	230	274	230	279	293	215	235
SHE	////	254	293	219	337	210	103	////	////	235
SH	372	303	215	254	244	308	376	254	////	283
BD	215	215	200	196	254	210	235	225	215	////
DK	240	236	234	304	266	256	258	256	262	318
GB	240	205	225	269	230	220	////	////	269	////
LB	240	/////	196	240	210	230	240	////	249	210
MT	337	303	215	196	176	264	176	176	196	191
SF	352	298	279	274	274	264	274	249	235	220
TK	313	313	279	210	274	220	205	210	210	244
AVG	**297**	**267**	**240**	**237**	**252**	**244**	**246**	**243**	**244**	**257**
STDEV	**59**	**43**	**36**	**33**	**49**	**33**	**62**	**39**	**41**	**45**

NAS

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	274	318	244	242	266	246	284	302	334	378
CV	322	364	276	240	242	278	248	256	276	256
DT	220	228	222	208	240	262	278	266	272	264
JB	242	238	250	218	218	288	212	270	274	276
LS	254	244	240	225	205	215	225	249	215	200
SL	////	240	230	230	254	230	264	225	259	284
SA	259	215	196	210	181	196	181	215	205	200
DB	357	254	264	303	235	200	259	240	274	235
GC	381	284	264	249	249	352	230	264	244	196
JL	308	318	279	269	254	269	269	259	284	249
LK	308	274	274	259	254	240	279	357	313	323
SHE	330	256	260	330	226	300	296	306	274	354
SH	318	244	274	313	230	284	230	240	191	230
BD	303	225	205	205	210	181	215	230	220	244
DK	248	234	330	////	242	260	332	278	288	392
GB	235	274	225	235	235	230	////	279	176	210
LB	323	259	259	210	269	254	////	235	220	230
MT	244	235	215	176	176	196	196	////	196	196
SF	313	298	274	235	235	274	200	225	235	244
TK	264	298	230	220	205	186	269	191	225	200
AVG	**290**	**265**	**250**	**241**	**231**	**247**	**248**	**257**	**249**	**258**
STDEV	**45**	**38**	**31**	**39**	**26**	**44**	**40**	**38**	**43**	**60**

DOWN

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	364	338	306	368	236	288	310	292	302	////
CV	252	310	276	216	326	304	274	276	272	////
DT	296	258	332	260	272	154	276	260	290	316
JB	192	208	286	228	226	230	252	244	282	264
LS	244	259	200	191	220	215	215	235	196	200
SL	293	264	279	298	357	284	////	////	259	////
SA	196	244	235	210	215	225	323	342	249	244
DB	269	347	264	298	279	376	230	249	469	////
GC	264	210	225	210	200	205	210	205	230	205
JL	357	274	269	284	328	259	240	230	284	240
LK	372	401	318	308	332	298	244	220	264	254
SHE	244	191	196	244	308	381	244	235	362	288
SH	////	298	////	259	279	////	244	274	254	230
BD	240	249	215	244	191	264	249	249	////	////
DK	228	250	418	278	274	290	314	294	440	388
GB	////	298	249	264	357	230	269	235	////	////
LB	298	279	244	254	235	210	313	244	308	249
MT	274	235	274	210	225	249	191	293	196	269
SF	337	332	288	318	298	288	303	288	303	284
TK	293	240	200	200	205	196	240	210	205	210
AVG	**278**	**274**	**267**	**257**	**268**	**260**	**260**	**257**	**287**	**260**
STDEV	**53**	**52**	**54**	**46**	**54**	**58**	**38**	**35**	**74**	**49**

UN

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	302	258	226	250	214	272	284	278	////	264
CV	372	296	262	298	320	278	286	286	310	366
DT	232	214	228	236	240	234	248	274	244	254
JB	230	234	216	240	262	256	262	250	270	268
LS	279	244	210	244	220	215	////	196	225	////
SL	////	244	288	////	249	240	210	254	249	240
SA	240	240	205	215	220	166	249	200	225	254
DB	274	240	191	215	225	215	293	220	196	264
GC	279	269	279	220	225	274	264	230	230	191
JL	328	274	269	264	284	259	200	220	249	284
LK	274	235	240	254	274	279	277	259	293	279
SHE	////	230	225	210	259	205	215	215	////	////
SH	430	347	279	279	205	298	244	259	264	259
BD	269	244	303	200	244	235	313	230	210	220
DK	234	240	268	276	266	////	////	334	////	274
GB	240	259	225	288	249	200	205	196	186	318
LB	288	254	196	230	264	254	244	200	191	200
MT	254	298	254	254	298	235	254	244	205	264
SF	372	303	303	259	284	249	269	264	269	269
TK	362	215	240	205	288	210	205	205	191	181
AVG	**292**	**257**	**245**	**244**	**254**	**241**	**251**	**241**	**236**	**258**
STDEV	**58**	**33**	**35**	**29**	**31**	**33**	**33**	**36**	**37**	**44**

UT

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	284	272	262	302	258	246	312	276	////	310
CV	374	274	350	264	306	350	262	238	318	298
DT	310	236	232	204	220	274	236	262	244	240
JB	274	202	204	218	274	232	246	266	282	274
LS	655	254	200	186	205	196	161	191	186	269
SL	259	254	200	220	210	171	225	210	235	240
SA	230	196	181	////	205	191	186	225	191	181
DB	254	269	244	215	220	200	181	225	200	328
GC	259	225	264	240	181	191	181	210	205	210
JL	396	308	308	313	303	318	274	347	303	308
LK	328	284	269	254	298	259	240	264	235	298
SHE	////	232	232	344	254	280	////	////	242	////
SH	288	337	259	259	264	220	274	279	220	200
BD	298	249	240	244	235	215	244	220	186	200
DK	236	260	272	366	278	268	282	290	////	////
GB	274	210	303	240	254	254	220	225	205	249
LB	308	259	230	230	240	269	293	284	249	210
MT	249	249	288	269	264	240	225	210	210	210
SF	396	274	230	259	259	313	323	293	244	288
TK	288	240	200	////	235	293	210	215	205	196
AVG	**314**	**254**	**248**	**257**	**248**	**249**	**241**	**249**	**231**	**251**
STDEV	**96**	**34**	**43**	**48**	**35**	**48**	**46**	**40**	**39**	**47**

DT

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	294	294	262	254	262	266	294	286	320	300
CV	256	230	228	260	258	364	290	284	262	292
DT	214	228	252	200	232	248	266	294	312	274
JB	224	302	298	234	250	244	256	288	286	286
LS	////	230	////	244	205	249	225	259	274	274
SL	////	274	372	240	396	240	527	254	269	279
SA	230	215	215	205	////	210	235	210	235	210
DB	259	205	147	210	200	196	200	225	191	////
GC	249	249	205	181	210	161	210	191	196	176
JL	293	347	////	318	269	////	249	303	////	352
LK	284	328	269	244	210	254	186	269	298	225
SHE	357	274	357	////	230	191	////	225	332	337
SH	318	196	259	244	244	225	249	249	240	215
BD	308	254	210	269	215	220	210	200	186	200
DK	274	244	328	224	302	254	268	376	270	288
GB	240	240	328	196	210	240	274	240	249	225
LB	332	240	205	200	200	240	244	220	205	215
MT	244	259	225	235	210	220	225	230	225	308
SF	411	288	264	254	259	279	298	269	357	274
TK	313	332	269	////	////	230	235	200	230	230
AVG	**283**	**261**	**261**	**234**	**242**	**238**	**260**	**254**	**260**	**261**
STDEV	**51**	**43**	**59**	**33**	**48**	**41**	**72**	**45**	**50**	**48**

DN

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	276	376	258	296	276	278	258	312	284	282
CV	288	278	354	290	284	240	260	248	290	270
DT	244	236	212	256	230	248	248	268	240	240
JB	////	190	254	202	230	////	264	276	272	230
LS	308	210	210	186	259	205	215	186	254	205
SL	313	264	249	293	264	259	264	////	308	////
SA	220	235	220	176	////	235	332	225	156	240
DB	323	313	269	259	303	220	264	////	386	274
GC	////	230	264	////	////	279	279	////	////	298
JL	303	288	284	342	318	284	323	288	254	////
LK	332	372	225	230	254	293	293	288	372	303
SHE	294	278	334	272	244	290	272	278	344	358
SH	396	313	279	205	288	274	328	////	288	220
BD	254	288	200	254	240	235	249	////	////	////
DK	266	232	242	268	226	246	280	310	280	336
GB	244	240	220	186	240	269	264	254	240	230
LB	342	279	274	274	230	279	254	235	284	269
MT	225	186	235	244	230	220	240	240	186	220
SF	332	279	298	235	293	249	274	288	313	328
TK	230	220	235	200	200	235	////	200	205	200
AVG	**288**	**265**	**256**	**246**	**256**	**255**	**272**	**260**	**275**	**265**
STDEV	**48**	**52**	**40**	**45**	**32**	**26**	**30**	**38**	**59**	**47**

APPENDIX for CHAPTER 4: Establishing the min number of saccadic eye movements required for a representative result

PEAK VELOCITY (Deg/sec) 40-59 years

TEM

Number of individual runs

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	475	502	468	502	529	516	496	523	574	509
CV	409	437	437	465	458	486	450	430	430	500
DT	494	449	494	464	487	456	479	479	494	502
JB	625	613	572	573	584	590	554	618	602	614
LS	359	359	307	333	384	359	333	359	359	333
SL	512	591	512	532	493	532	512	532	532	512
SA	519	519	452	502	502	486	502	486	486	469
DB	526	542	575	608	542	542	591	608	542	591
GC	458	493	493	458	493	493	493	528	528	493
JL	455	398	455	342	370	199	////	114	228	142
LK	392	411	411	392	392	392	373	392	429	////
SHE	585	////	463	536	610	876	561	585	512	512
SH	458	425	360	425	425	360	360	360	360	360
BD	522	522	522	457	522	522	457	522	391	522
DK	850	867	698	807	756	640	480	865	813	796
GB	347	284	315	315	347	379	315	284	315	315
LB	621	536	492	514	450	471	471	493	471	471
MT	297	315	353	297	353	315	315	241	353	353
SF	380	380	342	361	342	342	342	304	342	342
TK	426	446	446	466	466	486	446	446	426	426
AVG	**485**	**478**	**458**	**467**	**475**	**472**	**449**	**458**	**459**	**461**
STDEV	**123**	**129**	**96**	**118**	**102**	**141**	**85**	**161**	**127**	**138**

UP

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	250	204	276	237	295	263	197	230	217	290
CV	235	235	268	211	276	284	252	275	284	309
DT	381	428	354	366	381	369	369	350	353	323
JB	366	380	344	344	358	358	337	358	351	322
LS	218	218	249	218	218	187	187	218	218	218
SL	346	386	285	305	285	305	285	285	325	346
SA	157	296	296	244	209	244	////	209	262	209
DB	134	134	150	117	134	134	150	150	134	
GC	192	307	281	////	294	////	281	345	268	307
JL	324	300	347	254	208	277	208	324	277	277
LK	267	309	281	253	267	253	267	267	253	281
SHE	////	344	322	301	322	313	258	////	////	279
SH	297	270	243	270	243	270	297	270	////	243
BD	213	243	243	213	182	243	243	243	182	////
DK	165	173	197	259	299	252	244	236	236	275
GB	264	340	302	226	264	264	////	////	302	////
LB	300	////	285	240	270	225	240	////	225	240
MT	264	283	264	264	226	226	245	283	264	245
SF	276	290	276	247	247	276	261	261	305	261
TK	304	290	330	304	304	317	317	317	317	277
AVG	**260**	**286**	**280**	**256**	**264**	**266**	**258**	**272**	**265**	**277**
STDEV	**70**	**74**	**50**	**54**	**59**	**55**	**54**	**56**	**58**	**38**

NAS

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	266	222	242	252	276	281	301	286	306	281
CV	262	281	324	281	281	267	276	324	276	295
DT	303	308	298	292	313	282	271	292	292	333
JB	461	461	393	472	467	472	462	478	488	462
LS	290	342	158	237	263	158	184	290	237	211
SL	////	403	422	422	403	365	403	384	384	384
SA	278	261	244	226	226	226	226	226	209	226
DB	402	434	434	482	434	466	450	386	450	498
GC	260	297	334	297	334	297	334	297	297	334
JL	347	347	347	315	252	315	252	315	315	221
LK	283	250	250	200	250	283	217	267	217	267
SHE	325	416	380	398	380	325	325	307	361	342
SH	554	600	600	554	600	462	554	508	508	462
BD	458	458	458	458	458	524	458	458	524	458
DK	218	224	284	////	251	297	284	284	238	244
GB	350	350	350	350	350	350	////	350	300	350
LB	344	377	344	344	344	361	////	361	361	344
MT	264	326	244	346	264	326	264	////	224	224
SF	264	233	248	233	217	233	217	233	248	217
TK	385	368	385	368	402	385	368	351	335	385
AVG	**332**	**348**	**337**	**344**	**338**	**334**	**325**	**337**	**328**	**327**
STDEV	**87**	**96**	**99**	**100**	**99**	**92**	**103**	**78**	**98**	**92**

DOWN

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	209	292	292	222	279	292	285	310	279	////
CV	292	284	316	284	244	244	284	300	276	////
DT	338	415	404	317	338	770	321	286	289	432
JB	420	411	439	411	357	421	393	384	483	375
LS	314	341	262	341	314	341	314	341	341	314
SL	197	215	197	179	161	107	////	////	197	////
SA	361	301	261	261	301	341	261	241	220	261
DB	280	332	350	315	315	297	332	315	210	////
GC	288	313	313	300	288	288	300	275	325	300
JL	321	289	321	289	353	321	257	385	289	321
LK	322	348	348	295	308	335	308	335	295	322
SHE	323	323	323	398	348	348	348	323	323	522
SH	////	148	////	197	164	////	180	180	213	229
BD	179	149	149	75	149	179	149	149	////	////
DK	430	180	413	342	298	193	224	189	180	237
GB	////	300	246	273	300	246	273	218	////	////
LB	330	250	216	227	262	250	262	239	239	250
MT	243	210	324	275	243	243	550	275	227	275
SF	217	205	193	193	193	205	181	181	193	181
TK	263	276	263	224	237	421	224	237	250	224
AVG	**296**	**279**	**296**	**271**	**273**	**307**	**287**	**272**	**268**	**303**
STDEV	**70**	**76**	**78**	**78**	**65**	**138**	**89**	**69**	**73**	**91**

UN

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	358	364	341	364	347	381	353	324	////	318
CV	265	256	338	347	293	293	274	238	302	265
DT	483	477	428	397	459	476	477	488	421	453
JB	496	447	461	461	440	447	495	502	384	461
LS	286	305	305	286	248	286	////	248	248	////
SL	////	435	435	////	290	387	290	387	338	338
SA	226	226	226	264	264	226	188	151	188	188
DB	280	323	323	280	259	237	237	129	280	216
GC	230	287	230	258	230	172	230	201	230	230
JL	524	565	565	565	565	565	565	524	565	605
LK	263	319	301	225	225	225	169	225	150	150
SHE	////	317	285	317	317	222	317	254	////	////
SH	375	375	375	443	341	443	443	409	443	375
BD	217	248	248	186	217	248	248	217	186	155
DK	329	227	249	250	250	////	////	238	////	227
GB	348	348	313	313	313	278	313	313	278	278
LB	338	338	374	302	338	302	320	356	338	338
MT	205	273	239	171	239	239	239	205	273	273
SF	342	308	308	308	325	342	325	342	325	342
TK	320	280	280	200	240	240	240	240	280	240
AVG	**327**	**336**	**331**	**313**	**310**	**316**	**318**	**300**	**308**	**303**
STDEV	**95**	**88**	**88**	**100**	**90**	**106**	**111**	**115**	**104**	**117**

UT

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	221	238	267	261	226	279	238	249	/////	232
CV	374	342	358	350	342	358	334	334	318	374
DT	704	757	774	704	844	757	774	845	722	775
JB	577	607	577	577	623	570	576	564	619	630
LS	272	227	272	227	181	181	159	204	204	113
SL	536	536	514	491	514	491	491	469	559	536
SA	277	300	300	////	300	277	254	207	207	300
DB	405	456	431	405	355	431	405	355	355	456
GC	350	437	393	481	350	350	350	393	437	437
JL	512	614	512	512	614	461	614	461	461	512
LK	537	537	429	429	494	494	472	537	451	451
SHE	////	708	867	564	954	969	////	////	737	////
SH	393	393	393	393	393	393	327	393	393	327
BD	422	338	422	507	338	338	338	338	338	338
DK	630	474	532	498	490	360	524	352	////	////
GB	220	244	293	269	269	269	293	293	293	269
LB	299	299	315	266	266	232	315	232	266	282
MT	373	373	331	352	373	394	394	414	373	352
SF	406	387	387	387	387	369	350	387	387	369
TK	286	260	234	////	234	260	286	234	208	260
AVG	**410**	**426**	**430**	**426**	**427**	**412**	**395**	**382**	**407**	**390**
STDEV	**139**	**158**	**164**	**128**	**202**	**185**	**149**	**154**	**163**	**156**

DT

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	301	340	327	397	366	366	327	333	391	321
CV	298	307	262	298	262	298	289	262	262	289
DT	298	315	344	268	303	233	285	268	228	292
JB	547	524	509	562	479	509	463	501	456	479
LS	////	141	////	118	188	94	118	235	212	306
SL	////	182	205	228	137	205	160	228	160	182
SA	260	334	260	297	////	260	260	260	297	260
DB	353	331	331	353	309	331	309	309	287	////
GC	248	248	267	267	229	286	267	267	305	267
JL	302	327	////	226	251	////	176	226	////	251
LK	385	423	385	346	346	346	346	308	346	346
SHE	483	328	293	////	345	362	////	328	345	431
SH	255	191	212	212	212	170	170	234	212	234
BD	307	239	273	273	205	239	239	273	205	239
DK	316	268	316	208	381	321	208	357	268	350
GB	445	525	485	606	525	485	525	566	525	445
LB	412	460	412	436	412	387	363	387	387	363
MT	231	231	213	267	249	231	249	231	284	249
SF	243	277	208	208	243	277	277	243	277	243
TK	216	216	247	/////	/////	247	247	247	216	216
AVG	**328**	**310**	**308**	**310**	**302**	**297**	**278**	**303**	**298**	**303**
STDEV	**93**	**107**	**91**	**125**	**103**	**101**	**100**	**92**	**93**	**81**

DN

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	310	258	273	295	258	251	324	332	302	339
CV	322	313	286	322	331	322	305	294	358	278
DT	299	299	307	257	224	282	274	241	249	258
JB	////	477	402	423	418	////	477	413	450	427
LS	217	217	190	190	220	271	298	217	244	217
SL	249	226	226	181	226	226	249	////	203	////
SA	324	236	236	236	////	177	206	265	236	206
DB	353	235	259	188	282	235	212	////	165	282
GC	////	242	162	////	////	162	202	////	////	283
JL	179	202	224	292	202	157	224	179	157	////
LK	415	323	400	338	369	385	354	262	446	400
SHE	423	294	353	341	352	306	282	259	505	329
SH	355	400	355	355	311	400	400	////	355	355
BD	207	118	89	148	118	148	118	////	////	////
DK	255	236	176	143	217	181	223	264	185	176
GB	244	162	203	203	203	244	203	244	162	203
LB	406	386	406	406	325	426	345	345	386	406
MT	268	302	251	235	218	235	268	235	235	268
SF	243	205	205	224	205	205	205	205	187	224
TK	218	218	156	187	156	156	////	156	218	187
AVG	**294**	**267**	**258**	**261**	**258**	**251**	**272**	**261**	**280**	**285**
STDEV	**75**	**84**	**90**	**85**	**79**	**85**	**84**	**66**	**110**	**80**

APPENDIX for CHAPTER 4: Establishing the min number of saccadic eye movements required for a representative result

AMPLITUDE (Degrees) 40-59 years

TEM

Number of individual runs

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	10.66	10.67	10.74	10.82	11.49	10.52	11.23	10.97	11.19	10.67
CV	10.98	12.13	11.49	12.02	11.59	11.79	11.48	11.03	11.85	12.00
DT	12.57	13.14	12.32	13.46	13.34	13.16	12.96	13.22	12.99	13.22
JB	12.44	12.73	11.54	11.80	10.59	12.21	11.41	11.81	11.16	11.57
LS	10.00	10.88	9.25	9.50	10.13	10.38	10.38	9.63	10.38	10.00
SL	10.01	11.26	10.97	10.78	10.58	11.16	11.45	11.74	11.45	10.97
SA	13.33	13.41	12.75	13.00	12.92	13.00	13.00	12.10	12.43	12.43
DB	12.03	12.11	12.35	12.43	12.75	12.75	12.99	13.48	13.24	13.24
GC	10.66	11.18	10.49	11.01	9.97	12.04	9.97	9.97	11.69	10.83
JL	10.84	10.28	11.12	12.37	10.56	10.42	////	7.37	9.45	7.09
LK	10.66	10.94	11.39	11.58	10.85	10.30	10.48	11.03	11.94	////
SHE	8.62	////	7.50	7.89	8.63	8.87	7.11	7.11	7.02	6.29
SH	9.42	9.42	7.99	8.78	8.78	8.47	7.99	7.99	8.31	8.15
BD	11.79	11.47	11.15	11.15	11.79	11.79	11.79	9.24	8.92	8.92
DK	15.86	17.33	14.80	15.48	14.35	13.80	12.97	14.91	15.46	16.02
GB	8.94	8.63	8.01	10.01	9.40	11.55	9.86	8.16	9.55	11.40
LB	13.29	12.35	10.99	12.03	11.20	11.40	11.82	12.03	11.82	11.72
MT	9.69	9.69	10.87	9.42	9.15	9.15	8.70	7.34	10.42	10.42
SF	11.97	12.06	12.25	11.60	11.32	12.06	11.41	11.04	11.32	10.49
TK	9.99	9.89	11.28	10.59	10.69	10.88	10.49	10.29	10.29	9.89
AVG	**11.19**	**11.56**	**10.96**	**11.29**	**11.00**	**11.29**	**10.92**	**10.52**	**11.04**	**10.81**
STDEV	**1.75**	**1.90**	**1.73**	**1.72**	**1.52**	**1.44**	**1.67**	**2.18**	**1.88**	**2.25**

NAS

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	8.31	8.15	8.52	7.19	8.26	8.99	9.14	9.94	8.74	9.10
CV	8.14	8.22	8.46	8.11	8.04	7.74	8.39	8.62	8.15	8.74
DT	7.81	8.43	7.38	7.59	7.44	7.40	7.06	8.06	7.37	8.38
JB	10.79	11.05	7.78	11.36	11.53	10.70	11.41	10.63	10.69	10.06
LS	9.26	9.64	6.81	6.94	7.46	6.81	7.97	8.61	7.84	8.48
SL	////	10.41	11.62	10.97	11.25	11.06	11.25	12.00	10.31	10.12
SA	8.41	8.07	7.90	7.14	6.71	6.80	7.31	6.20	6.97	6.71
DB	11.30	11.69	10.20	13.03	11.06	12.08	11.38	9.89	12.01	12.55
GC	7.07	7.98	7.80	7.98	12.34	8.34	8.71	7.98	8.16	8.34
JL	9.24	8.78	8.62	9.24	9.24	8.93	8.47	8.93	9.24	9.70
LK	7.81	7.65	7.40	6.91	7.56	7.00	6.83	7.00	7.48	8.22
SHE	9.00	9.43	8.75	9.61	8.35	9.18	8.46	9.11	8.93	7.95
SH	11.95	13.75	13.30	12.85	13.75	11.72	12.17	11.95	11.50	11.05
BD	11.19	11.83	10.87	10.23	9.59	12.15	11.51	11.51	10.55	11.51
DK	4.40	6.17	6.29	////	5.58	7.64	6.29	6.12	6.04	6.21
GB	10.73	10.98	9.76	9.02	10.24	8.78	////	9.51	9.76	8.78
LB	9.29	10.17	8.65	9.37	9.53	9.37	////	9.93	9.37	9.21
MT	7.95	10.73	7.95	10.03	8.64	8.94	8.64	////	9.04	8.24
SF	9.54	9.39	9.01	9.09	9.01	9.31	8.78	8.33	9.01	9.62
TK	10.21	9.80	10.05	9.89	9.80	9.97	9.31	9.56	9.80	10.21
AVG	**9.07**	**9.62**	**8.86**	**9.29**	**9.27**	**9.15**	**9.06**	**9.15**	**9.05**	**9.16**
STDEV	**1.78**	**1.77**	**1.70**	**1.85**	**2.01**	**1.70**	**1.78**	**1.70**	**1.53**	**1.52**

UP

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	8.27	9.43	10.06	10.61	9.22	10.31	10.31	9.97	7.93	10.30
CV	9.88	9.56	11.13	10.53	10.42	8.97	9.92	10.14	9.54	10.19
DT	9.57	9.73	8.61	8.91	9.59	9.25	9.84	8.37	9.16	9.02
JB	8.03	8.31	8.63	8.41	8.35	7.24	8.75	8.27	7.40	8.44
LS	7.14	7.29	6.99	7.14	7.59	6.83	6.99	6.68	7.74	8.35
SL	9.23	9.53	7.54	8.83	8.24	7.84	7.64	7.74	8.63	8.24
SA	9.88	9.36	10.56	10.30	8.34	8.00	////	9.88	9.71	9.02
DB	7.35	8.16	7.67	6.53	8.08	7.02	7.10	6.37	7.10	////
GC	6.18	9.67	9.48	////	9.67	////	10.04	12.48	9.55	9.61
JL	7.90	7.67	9.37	9.03	10.27	10.27	11.51	9.93	9.93	8.58
LK	8.09	8.71	8.50	7.54	8.30	7.34	8.16	8.71	7.88	8.16
SHE	////	10.28	9.33	9.12	9.75	9.75	7.66	////	////	8.60
SH	9.76	10.81	9.62	9.76	8.96	8.70	9.49	10.81	////	8.70
BD	11.42	13.20	13.35	11.57	13.05	15.28	14.83	14.98	13.94	////
DK	7.92	8.69	8.96	7.39	10.11	8.24	9.07	8.60	8.76	11.04
GB	4.97	5.71	6.63	4.42	6.26	4.24	////	////	6.63	////
LB	8.78	////	8.64	8.49	8.78	8.93	9.22	////	7.32	8.93
MT	8.74	9.57	9.47	9.29	7.63	6.99	9.38	9.38	10.21	8.28
SF	9.00	10.49	9.71	9.99	9.35	10.06	9.49	9.92	10.63	9.71
TK	9.67	9.15	9.88	9.54	9.92	10.89	10.83	10.25	10.57	8.31
AVG	**8.51**	**9.23**	**9.21**	**8.81**	**9.09**	**8.74**	**9.46**	**9.56**	**9.04**	**9.03**
STDEV	**1.48**	**1.54**	**1.50**	**1.67**	**1.41**	**2.25**	**1.83**	**2.05**	**1.74**	**0.85**

DOWN

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	7.06	8.61	8.35	7.14	9.55	9.71	9.13	10.72	8.87	////
CV	9.47	7.98	8.86	8.37	7.40	8.57	8.02	8.86	8.16	////
DT	9.85	8.83	8.67	8.45	8.15	8.26	7.87	7.41	7.41	7.32
JB	8.85	10.56	9.98	14.51	10.73	10.24	9.43	11.11	11.15	9.69
LS	7.16	8.44	7.16	9.34	7.29	9.08	8.31	8.83	8.70	8.31
SL	4.81	7.70	5.60	5.34	4.29	5.25	////	////	6.12	////
SA	11.26	8.42	7.73	9.59	13.12	13.60	8.22	7.83	7.54	8.12
DB	6.66	9.31	9.31	9.99	6.75	7.94	10.25	9.39	9.22	////
GC	9.47	9.41	9.65	9.65	9.90	9.22	9.83	8.25	10.51	10.20
JL	5.49	6.74	8.46	7.68	9.72	12.07	11.44	8.62	7.68	11.60
LK	8.70	8.96	8.83	7.79	8.18	7.46	7.92	7.79	7.52	8.31
SHE	8.62	8.26	8.87	10.32	8.74	7.41	8.14	7.53	7.29	9.23
SH	////	4.16	////	5.36	5.22	////	5.20	4.80	6.16	6.16
BD	6.34	5.32	7.22	5.97	6.85	6.85	6.56	4.37	////	////
DK	10.99	5.63	8.96	9.45	8.14	5.06	5.71	5.02	4.87	6.28
GB	////	8.93	7.07	8.27	9.07	6.93	8.40	7.87	////	////
LB	9.77	8.33	7.33	7.38	8.66	7.61	8.99	7.94	7.72	8.05
MT	7.51	6.40	10.44	7.35	7.27	7.19	11.62	8.22	7.27	8.30
SF	6.71	7.30	7.59	7.12	6.53	7.36	6.47	7.24	6.47	6.00
TK	8.29	8.42	7.97	6.56	6.81	10.61	6.81	7.84	7.65	6.04
AVG	**8.17**	**7.89**	**8.32**	**8.28**	**8.12**	**8.44**	**8.33**	**7.87**	**7.80**	**8.12**
STDEV	**1.82**	**1.55**	**1.18**	**2.08**	**1.97**	**2.14**	**1.75**	**1.73**	**1.52**	**1.68**

UN

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	10.98	11.89	11.21	12.03	10.86	11.44	11.89	11.45	////	10.65
CV	10.53	7.89	10.23	7.57	10.11	10.31	9.47	9.56	10.84	8.97
DT	11.68	11.90	10.80	9.61	11.18	11.59	12.15	11.69	9.81	11.07
JB	10.00	8.98	10.10	9.94	8.99	10.00	10.15	10.93	7.97	9.79
LS	8.01	10.43	8.85	10.62	10.90	10.80	////	10.90	12.57	////
SL	////	12.03	12.98	////	12.03	11.09	9.91	13.21	11.56	11.80
SA	9.94	11.78	12.51	11.96	11.41	9.75	10.31	8.83	9.75	9.57
DB	7.68	8.84	8.42	7.58	8.52	7.37	6.10	6.52	7.47	7.26
GC	9.54	9.25	9.25	10.10	9.68	9.68	9.25	9.11	9.39	8.83
JL	13.20	11.42	12.21	12.80	14.38	14.97	15.56	16.35	17.73	16.15
LK	7.80	8.07	8.62	7.06	6.51	6.79	5.50	6.70	6.06	6.15
SHE	////	10.07	9.45	9.14	10.38	7.90	9.76	10.07	////	////
SH	11.97	12.30	13.30	13.80	9.81	14.47	14.13	13.30	14.30	13.14
BD	6.37	7.88	8.19	7.28	7.88	9.10	7.28	8.49	5.91	6.21
DK	10.02	9.41	7.96	10.30	6.78	////	////	9.32	////	8.98
GB	9.17	8.15	8.66	7.81	7.64	7.98	7.64	7.81	7.13	7.47
LB	11.21	11.55	11.73	10.42	10.77	9.99	10.77	11.38	10.51	10.77
MT	6.83	12.16	10.33	8.66	10.16	7.16	11.00	10.83	10.33	13.50
SF	10.86	8.85	9.52	9.52	9.69	11.36	10.44	10.94	10.86	10.69
TK	11.15	12.71	13.10	10.36	10.95	12.71	11.34	10.56	11.93	11.93
AVG	**9.83**	**10.28**	**10.37**	**9.82**	**9.93**	**10.23**	**10.15**	**10.40**	**10.24**	**10.16**
STDEV	**1.87**	**1.71**	**1.76**	**1.91**	**1.86**	**2.29**	**2.53**	**2.31**	**2.99**	**2.61**

UT

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	10.05	10.03	11.68	11.83	12.47	10.70	10.07	11.19	////	12.34
CV	11.18	9.93	9.93	10.33	10.11	9.32	9.99	9.83	10.89	10.50
DT	16.19	17.77	17.28	17.70	19.35	17.24	16.54	18.54	16.79	17.17
JB	11.33	12.00	11.22	11.25	12.00	11.34	11.49	11.15	11.86	11.58
LS	6.42	5.98	7.64	6.86	6.53	6.09	6.20	6.42	6.31	5.87
SL	11.24	11.56	11.45	11.78	11.67	11.02	11.78	11.89	12.44	12.33
SA	6.98	9.90	9.34	////	8.78	8.89	9.57	8.33	6.87	10.02
DB	10.02	10.64	11.14	10.77	10.27	10.39	11.01	9.28	10.02	12.13
GC	7.25	10.03	8.11	10.24	8.11	9.81	6.61	8.96	9.39	8.96
JL	11.74	11.99	11.99	11.74	12.24	11.49	11.99	10.49	10.24	10.74
LK	11.85	11.85	12.58	10.90	11.85	10.90	11.85	11.74	11.95	11.85
SHE	////	11.50	11.59	11.33	15.12	13.01	////	////	9.94	////
SH	11.19	10.55	12.79	9.59	9.27	8.95	10.55	9.27	9.59	8.95
BD	13.19	11.96	11.54	13.61	14.02	13.19	11.13	11.54	11.13	13.19
DK	11.93	9.24	9.41	8.77	8.87	8.36	6.76	6.89	////	////
GB	7.16	8.36	7.40	7.88	8.00	8.00	8.47	8.59	8.59	9.31
LB	9.48	9.73	9.73	8.51	9.24	7.21	9.40	9.73	8.75	8.67
MT	12.84	13.65	10.62	13.15	13.55	13.15	12.34	12.84	12.44	12.54
SF	10.80	11.70	10.71	11.07	11.52	11.07	9.81	10.62	9.72	10.17
TK	11.06	10.80	10.93	////	9.66	12.83	12.83	10.17	9.66	10.93
AVG	**10.63**	**10.96**	**10.85**	**10.96**	**11.13**	**10.65**	**10.44**	**10.39**	**10.37**	**10.96**
STDEV	**2.41**	**2.28**	**2.15**	**2.42**	**2.94**	**2.53**	**2.44**	**2.58**	**2.33**	**2.38**

DT

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	9.63	10.15	11.11	9.46	10.13	9.68	9.47	9.81	10.04	11.33
CV	8.50	7.10	7.74	7.13	7.19	8.18	7.93	6.84	6.75	7.87
DT	7.92	8.98	8.46	7.60	7.71	7.04	7.89	6.92	7.76	8.04
JB	11.38	10.82	10.69	13.99	12.61	12.03	12.53	10.38	9.68	11.27
LS	////	4.94	////	4.02	3.44	3.67	4.25	7.00	6.54	6.08
SL	////	5.01	5.56	6.57	4.56	5.01	5.12	6.57	4.34	4.45
SA	6.53	9.07	7.44	7.80	////	7.08	6.53	7.26	7.44	7.62
DB	8.40	7.76	9.16	7.76	7.76	7.65	7.97	7.65	7.76	////
GC	5.95	6.14	6.14	6.42	5.49	6.88	6.04	6.14	6.51	6.42
JL	6.26	6.51	////	6.02	5.89	////	6.75	6.51	////	6.26
LK	9.01	9.95	9.20	8.45	8.26	8.07	8.64	7.32	7.70	8.64
SHE	9.01	7.66	6.90	////	6.31	8.17	////	7.41	7.41	9.68
SH	5.70	4.67	4.77	4.46	4.88	3.53	4.67	5.08	5.19	5.29
BD	7.67	5.00	6.34	8.34	6.51	6.51	5.50	6.84	5.50	7.84
DK	7.05	8.20	7.73	7.57	7.30	7.91	7.44	8.28	9.23	8.28
GB	10.07	12.24	12.63	15.59	12.24	12.63	14.21	13.82	13.62	11.25
LB	10.52	11.47	10.99	11.11	10.29	10.17	9.93	9.22	9.93	9.69
MT	7.12	7.03	6.60	6.33	9.20	7.90	7.81	6.68	9.20	7.12
SF	7.79	8.72	8.13	8.21	9.97	9.06	9.31	7.96	9.40	8.89
TK	4.97	4.06	5.72	////	////	6.32	5.57	6.17	5.42	5.42
AVG	**7.97**	**7.77**	**8.07**	**8.16**	**7.76**	**7.76**	**7.77**	**7.69**	**7.86**	**7.97**
STDEV	**1.76**	**2.40**	**2.19**	**2.93**	**2.58**	**2.37**	**2.58**	**1.92**	**2.21**	**2.06**

DN

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	9.49	8.15	9.25	9.87	9.84	9.77	9.77	9.68	10.82	10.26
CV	9.06	8.47	7.77	7.59	9.18	7.82	7.70	7.91	9.18	8.05
DT	7.27	7.07	7.64	6.87	6.26	7.49	7.12	6.76	6.38	7.31
JB	////	12.89	9.65	10.65	11.91	////	12.45	10.29	10.89	9.47
LS	5.56	5.30	6.09	6.35	6.75	7.15	7.15	5.56	6.22	6.75
SL	4.96	5.30	4.96	4.63	5.18	4.96	6.07	////	4.96	////
SA	5.90	6.19	6.76	7.19	////	5.04	5.61	6.76	6.47	5.61
DB	8.04	6.55	7.01	7.01	7.81	6.78	6.32	////	5.29	6.55
GC	////	4.93	3.15	////	////	3.35	4.73	////	////	6.90
JL	3.40	3.51	4.27	5.26	3.72	3.72	4.27	3.61	3.51	////
LK	8.64	8.79	9.46	8.56	8.94	8.11	9.16	7.74	10.37	9.31
SHE	8.60	6.04	7.78	7.07	7.68	7.10	6.49	5.64	7.66	7.97
SH	5.64	6.94	5.64	7.59	6.29	6.72	6.50	////	6.72	6.29
BD	3.76	2.74	2.02	3.18	2.31	2.74	2.89	////	////	////
DK	6.52	5.07	4.75	4.32	4.86	4.61	4.83	4.91	4.62	4.60
GB	6.94	6.15	6.55	6.35	5.36	6.74	6.55	6.94	5.36	6.15
LB	10.11	10.70	11.20	10.51	9.02	11.10	9.81	10.21	10.51	11.20
MT	7.37	8.68	7.04	6.30	5.57	9.41	9.99	5.73	6.14	5.98
SF	8.20	7.84	7.84	8.02	8.20	7.84	8.02	7.47	7.66	8.75
TK	4.88	5.03	4.27	4.88	4.42	4.11	////	3.66	5.79	5.03
AVG	**6.91**	**6.82**	**6.65**	**6.96**	**6.85**	**6.56**	**7.13**	**6.86**	**7.14**	**7.42**
STDEV	**1.96**	**2.39**	**2.32**	**2.03**	**2.43**	**2.28**	**2.34**	**2.11**	**2.30**	**1.87**

APPENDIX for CHAPTER 4: Establishing the min number of saccadic eye movements required for a representative result

DURATION (msecs) 40-59 years

TEM

Number of individual runs

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	50	54	64	56	54	52	60	52	48	52
CV	48	54	50	54	44	48	48	48	50	40
DT	44	48	36	44	48	44	46	42	42	44
JB	36	42	36	42	32	42	38	36	34	34
LS	39	39	39	39	39	44	44	34	39	44
SL	34	34	39	34	34	34	34	39	34	34
SA	39	44	44	44	39	44	39	39	39	39
DB	34	34	34	39	39	39	39	39	44	39
GC	39	34	34	39	49	39	34	29	39	34
JL	34	39	34	54	39	68	////	103	59	64
LK	39	39	39	44	39	39	39	44	44	////
SHE	30	////	48	32	28	30	46	42	40	40
SH	49	34	34	34	49	39	44	29	54	39
BD	34	54	39	39	34	44	39	78	68	59
DK	34	34	34	34	36	38	58	28	30	34
GB	39	49	39	54	44	59	49	44	59	64
LB	39	39	39	39	39	39	39	44	44	39
MT	44	44	49	44	39	49	44	44	49	49
SF	49	44	54	49	49	49	49	54	54	49
TK	34	34	39	34	39	34	34	39	39	39
AVG	**39**	**42**	**41**	**42**	**41**	**44**	**43**	**45**	**45**	**44**
STDEV	**6**	**7**	**8**	**7**	**7**	**9**	**7**	**17**	**10**	**10**

UP

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	60	138	90	102	70	94	102	84	80	82
CV	62	68	62	80	66	52	68	64	64	58
DT	38	32	36	36	42	42	44	42	42	50
JB	40	38	52	44	38	34	68	50	38	52
LS	64	49	44	49	54	49	68	49	54	78
SL	44	44	39	49	49	44	54	39	49	39
SA	112	73	78	98	68	68	////	98	83	83
DB	78	83	78	73	93	78	78	68	78	////
GC	78	73	73	////	73	////	78	73	78	68
JL	44	38	68	93	93	88	122	78	88	68
LK	49	49	49	44	54	44	49	49	49	49
SHE	////	54	59	73	54	59	59	////	////	54
SH	64	78	78	68	68	50	68	73	////	68
BD	88	88	93	103	103	103	98	112	108	////
DK	104	124	80	64	72	84	66	70	78	84
GB	24	29	39	39	44	34	////	////	44	////
LB	44	////	59	68	59	68	73	////	54	68
MT	49	49	59	54	49	44	54	59	59	54
SF	68	78	68	78	83	78	78	73	83	73
TK	49	54	54	54	64	68	73	64	64	44
AVG	**61**	**65**	**63**	**67**	**65**	**62**	**72**	**67**	**66**	**63**
STDEV	**23**	**29**	**17**	**21**	**18**	**21**	**19**	**19**	**19**	**14**

NAS

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	52	66	56	56	50	54	52	64	52	50
CV	52	50	48	46	50	48	48	48	54	52
DT	44	46	42	42	42	44	42	44	44	42
JB	38	36	28	36	36	32	40	32	32	30
LS	44	39	54	44	44	64	64	49	49	59
SL	////	39	44	39	44	44	39	44	39	39
SA	44	44	49	44	44	44	44	44	49	44
DB	39	39	49	39	39	39	59	39	54	39
GC	34	39	34	39	49	39	39	39	59	39
JL	39	49	44	49	64	49	49	44	54	78
LK	39	44	39	44	44	39	54	39	59	49
SHE	58	56	62	56	62	64	56	58	66	54
SH	34	34	34	39	39	44	49	49	39	39
BD	44	39	68	54	44	54	39	39	54	44
DK	30	40	34	////	30	42	32	32	38	38
GB	49	54	49	49	44	44	////	44	54	39
LB	39	44	44	44	49	44	////	44	44	44
MT	44	54	49	49	54	44	49	////	54	64
SF	54	58	54	54	54	54	54	49	54	59
TK	39	39	44	34	34	34	34	34	39	39
AVG	**43**	**45**	**46**	**45**	**46**	**46**	**47**	**44**	**49**	**47**
STDEV	**7**	**8**	**10**	**7**	**8**	**8**	**9**	**8**	**9**	**11**

DOWN

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	76	52	54	60	64	58	56	64	52	////
CV	56	62	50	56	54	68	60	62	54	////
DT	44	34	34	48	32	34	34	38	36	32
JB	38	40	38	54	48	38	42	44	36	40
LS	34	44	39	49	39	44	44	44	44	44
SL	34	64	39	44	39	73	////	////	49	////
SA	54	39	44	54	83	59	44	44	49	44
DB	34	39	39	39	49	39	39	39	54	////
GC	49	44	44	49	59	49	49	44	54	59
JL	44	49	49	54	59	103	93	44	44	68
LK	44	39	39	39	39	49	39	39	39	44
SHE	44	39	39	39	44	34	39	39	44	34
SH	////	39	////	39	44	////	44	39	44	44
BD	54	59	103	78	73	68	68	44	////	////
DK	38	42	36	50	54	46	48	40	44	46
GB	////	44	39	44	44	39	44	44	////	////
LB	49	49	44	49	49	44	49	49	49	49
MT	44	39	54	39	39	39	44	44	49	39
SF	44	49	54	49	49	49	54	59	49	49
TK	49	44	44	39	44	39	44	44	44	44
AVG	**46**	**45**	**46**	**49**	**50**	**51**	**49**	**45**	**46**	**45**
STDEV	**10**	**8**	**15**	**10**	**12**	**17**	**13**	**8**	**6**	**9**

UN

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	60	62	72	68	62	64	70	60	////	64
CV	90	58	60	62	76	72	74	84	74	58
DT	40	40	44	42	44	38	44	40	42	42
JB	34	32	36	32	32	36	30	38	30	34
LS	44	78	73	78	73	54	////	78	93	////
SL	////	44	73	////	83	39	56	83	78	68
SA	88	103	112	98	93	93	103	117	112	98
DB	39	44	39	39	44	44	34	68	39	49
GC	117	83	103	108	108	122	93	103	108	103
JL	59	44	44	39	49	49	68	73	68	49
LK	39	39	39	49	44	44	39	44	54	54
SHE	////	103	83	73	108	88	73	88	////	////
SH	78	78	78	49	44	68	59	59	64	64
BD	44	59	68	68	54	73	54	98	54	68
DK	74	88	62	86	40	////	////	84	////	96
GB	44	44	49	44	44	49	44	49	49	44
LB	49	49	44	49	44	54	54	54	54	49
MT	59	68	88	69	88	59	98	78	83	98
SF	49	44	44	44	44	54	49	49	49	49
TK	93	93	112	93	98	117	108	103	108	112
AVG	61	63	66	63	64	64	64	72	68	67
STDEV	24	23	24	22	25	25	24	23	25	24

UT

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	80	78	90	86	116	82	88	98	////	102
CV	58	56	54	50	54	50	56	54	62	52
DT	40	44	42	44	42	44	38	38	40	38
JB	38	36	30	32	32	34	34	32	32	30
LS	39	34	39	39	44	54	68	49	49	93
SL	39	39	44	39	39	39	44	39	39	39
SA	39	49	49	////	49	49	54	59	54	59
DB	44	39	44	44	44	39	44	39	44	44
GC	34	49	44	59	44	44	39	44	39	54
JL	39	39	59	34	34	59	29	54	44	39
LK	39	44	49	49	39	39	49	44	49	44
SHE	////	36	38	42	36	34	////	////	38	////
SH	////	39	59	39	44	39	64	44	39	54
BD	59	59	49	68	73	68	54	64	54	73
DK	36	38	38	42	36	42	28	38	////	////
GB	44	54	39	49	44	44	44	49	54	49
LB	59	59	59	59	59	59	54	73	59	54
MT	59	59	49	59	68	49	64	54	59	54
SF	39	54	44	49	54	49	49	44	44	49
TK	83	78	83	////	73	98	93	88	83	83
AVG	48	49	50	49	51	51	52	53	49	56
STDEV	15	13	15	13	20	16	18	17	12	20

DT

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	58	48	56	50	54	46	46	50	46	54
CV	56	44	50	44	42	50	46	46	44	52
DT	46	50	40	50	42	48	44	40	58	42
JB	36	34	34	42	42	36	40	36	32	38
LS	////	59	////	48	34	64	59	59	49	39
SL	////	39	39	39	49	34	44	44	34	44
SA	34	39	44	39	////	34	39	39	54	44
DB	44	34	39	34	34	34	39	34	49	////
GC	34	34	34	34	34	34	34	34	34	34
JL	39	29	////	49	34	////	68	44	////	39
LK	34	34	34	34	34	34	39	34	34	34
SHE	29	54	34	////	49	34	////	34	34	34
SH	34	34	29	29	34	34	39	29	34	34
BD	39	39	39	54	44	64	49	44	44	54
DK	40	48	46	56	38	38	60	42	68	38
GB	39	39	49	44	39	44	49	39	44	59
LB	39	44	44	39	39	39	44	39	39	39
MT	44	44	44	54	49	44	49	39	44	39
SF	49	49	54	54	64	44	49	49	49	54
TK	39	29	32	////	////	44	34	39	44	34
AVG	41	41	41	44	42	42	46	41	44	42
STDEV	8	8	8	8	8	9	9	7	9	8

DN

Sbjs	1	2	3	4	5	6	7	8	9	10
AP	56	56	64	56	68	62	50	48	54	52
CV	48	46	48	40	50	44	46	42	48	56
DT	40	42	46	50	54	50	46	48	44	50
JB	////	44	36	38	40	////	38	42	36	34
LS	39	34	44	44	44	39	39	34	34	44
SL	29	34	29	39	34	29	39	////	44	////
SA	34	39	44	44	////	44	34	39	44	39
DB	34	39	39	54	44	39	44	////	54	39
GC	////	34	29	////	////	39	44	////	////	54
JL	29	29	29	34	29	34	34	29	39	////
LK	34	39	34	39	39	44	34	39	39	34
SHE	40	58	44	50	44	46	38	42	46	54
SH	24	39	29	34	39	34	29	////	34	24
BD	29	39	29	44	34	39	39	////	////	////
DK	44	40	42	42	40	42	38	36	38	38
GB	54	49	44	49	39	44	44	44	39	44
LB	39	44	44	44	44	44	44	49	44	44
MT	39	44	39	39	39	73	64	34	39	34
SF	44	54	54	54	54	54	54	49	59	54
TK	39	39	39	39	39	39	////	39	44	64
AVG	39	42	40	44	43	44	42	41	43	45
STDEV	8	7	9	7	9	10	8	6	7	10

APPENDIX for CHAPTER 4: Establishing the min number of saccadic eye movements required for a representative result

LATENCY (msecs) 60-89 years

TEM Number of individual runs

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	357	469	445	342	381	391	254	////	////	////
HC	256	308	334	330	274	302	320	622	332	352
IG	564	390	398	368	328	306	298	340	464	378
JO	308	////	308	269	367	288	293	220	235	230
MS	296	284	320	346	262	228	248	276	344	382
VG	391	391	347	298	401	352	367	347	318	381
WS	264	225	235	249	284	230	230	225	249	240
BW	290	252	212	246	////	290	256	282	254	344
ES	314	236	220	262	264	220	238	234	280	266
HR	422	448	280	322	262	340	348	332	348	286
JHE	269	191	191	220	////	230	210	196	240	205
JR	260	254	242	340	282	230	256	270	308	304
WC	////	274	249	210	244	215	230	288	269	249
DBE	////	336	342	376	340	272	340	390	260	220
HO	200	////	356	266	454	384	194	112	572	384
IB	430	240	210	205	225	220	196	259	259	200
JHO	484	306	290	254	296	272	268	296	608	304
MBU	533	264	279	200	244	200	210	200	210	323
RT	220	164	152	154	248	238	206	262	////	212
WHS	308	////	176	269	215	332	357	249	401	279
AVG	**343**	**296**	**279**	**276**	**298**	**277**	**266**	**284**	**331**	**292**
STDEV	**106**	**86**	**77**	**62**	**66**	**59**	**56**	**103**	**114**	**65**

NAS

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	////	235	215	////	230	249	210	269	244	284
HC	326	284	286	240	304	320	236	354	282	248
IG	428	228	224	316	268	274	////	312	312	374
JO	298	274	215	230	225	230	240	230	230	244
MS	316	284	270	280	282	272	242	258	282	318
VG	269	411	235	288	240	391	244	274	284	284
WS	293	240	249	220	269	254	249	225	225	235
BW	454	368	300	304	222	256	242	272	////	280
ES	304	292	250	218	252	248	256	290	236	264
HR	376	276	280	250	338	312	256	302	302	276
JHE	225	240	205	210	////	191	186	220	181	225
JR	238	224	272	200	304	246	278	268	246	260
WC	332	230	244	210	225	279	225	303	235	210
DBE	266	200	360	284	364	256	356	328	332	386
HO	312	////	224	210	////	318	450	288	352	38
IB	264	230	215	240	225	230	205	200	225	254
JHO	276	282	250	262	322	326	308	322	328	342
MBU	318	244	279	191	186	205	244	298	215	215
RT	236	286	248	182	////	310	////	366	300	266
WHS	425	259	////	298	259	337	332	313	342	367
AVG	**313**	**268**	**254**	**244**	**265**	**275**	**264**	**285**	**271**	**268**
STDEV	**66**	**51**	**38**	**41**	**48**	**49**	**63**	**44**	**49**	**75**

UP

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	////	430	269	367	264	298	////	303	347	235
HC	336	258	294	248	312	246	260	268	288	284
IG	////	302	394	290	336	////	302	////	////	304
JO	254	308	298	249	235	220	205	225	220	215
MS	302	262	224	248	272	284	250	280	300	312
VG	367	347	225	235	264	230	279	323	259	303
WS	293	230	264	254	225	254	274	264	259	225
BW	376	282	294	286	306	250	282	294	326	310
ES	296	////	222	////	252	252	302	260	262	244
HR	348	268	342	280	322	262	282	412	348	378
JHE	347	259	225	235	215	210	230	215	230	230
JR	264	274	262	234	294	240	286	282	292	286
WC	313	205	////	205	205	254	215	215	264	205
DBE	278	232	////	362	248	266	268	504	////	338
HO	314	302	340	292	////	232	////	318	370	370
IB	264	200	220	215	220	225	215	240	288	230
JHO	280	300	282	258	278	280	270	260	324	322
MBU	288	269	235	269	269	249	244	230	254	186
RT	242	212	252	260	268	////	278	258	278	302
WHS	406	298	284	235	440	225	372	196	288	318
AVG	**309**	**276**	**274**	**264**	**275**	**249**	**267**	**281**	**289**	**280**
STDEV	**45**	**54**	**49**	**43**	**54**	**24**	**39**	**73**	**41**	**55**

DOWN

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	357	288	259	288	318	240	328	254	225	323
HC	328	254	352	266	314	366	276	318	332	360
IG	396	328	276	274	264	////	288	476	420	412
JO	288	254	249	249	220	288	249	259	230	249
MS	312	226	232	262	238	300	298	310	296	314
VG	396	303	284	279	362	328	328	235	425	244
WS	293	264	230	205	220	215	240	////	240	244
BW	316	332	300	272	252	308	292	324	290	314
ES	292	304	370	298	258	296	320	274	284	252
HR	////	820	478	350	432	312	276	356	402	396
JHE	259	////	303	318	254	269	235	////	244	298
JR	314	286	236	250	238	324	402	260	296	330
WC	293	225	240	225	210	249	274	220	249	240
DBE	314	380	384	260	294	398	362	292	370	316
HO	368	336	336	////	288	286	252	356	282	274
IB	303	303	284	288	323	264	259	254	////	264
JHO	306	332	302	304	346	338	338	////	////	364
MBU	332	259	230	205	244	284	293	215	215	279
RT	250	310	298	296	282	272	322	280	264	256
WHS	376	347	249	269	264	313	240	244	288	235
AVG	**321**	**324**	**295**	**272**	**281**	**297**	**293**	**290**	**297**	**298**
STDEV	**42**	**127**	**64**	**36**	**55**	**44**	**44**	**64**	**67**	**54**

UN

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	////	411	264	362	254	254	269	274	386	279
HC	278	264	344	294	298	288	272	266	////	294
IG	306	306	254	278	262	340	252	338	470	338
JO	264	235	244	337	220	210	249	220	240	215
MS	290	272	290	250	256	254	248	262	262	284
VG	362	342	269	259	274	284	318	244	249	240
WS	318	249	230	215	225	279	210	220	284	205
BW	432	282	266	300	244	264	280	296	266	296
ES	312	256	////	266	240	256	276	304	256	242
HR	304	286	254	256	276	288	312	280	306	360
JHE	////	235	210	215	200	230	210	215	220	210
JR	268	260	278	234	398	298	326	320	268	298
WC	244	240	274	210	200	////	479	259	////	////
DBE	442	300	328	274	264	266	272	262	////	306
HO	////	302	////	456	380	526	452	530	416	356
IB	293	269	259	225	225	205	225	254	259	220
JHO	358	238	240	268	268	276	304	264	288	////
MBU	318	284	215	200	264	244	230	259	230	215
RT	330	258	294	260	328	268	296	276	312	////
WHS	406	372	269	440	202	264	274	372	328	391
AVG	**325**	**283**	**266**	**280**	**264**	**279**	**288**	**286**	**296**	**279**
STDEV	**58**	**47**	**34**	**71**	**54**	**67**	**70**	**69**	**69**	**59**

DT

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	284	220	////	254	////	318	259	235	323	////
HC	302	450	304	368	266	392	324	302	356	296
IG	658	286	294	278	324	726	316	384	292	////
JO	323	210	269	269	210	313	259	230	220	////
MS	304	224	314	154	286	302	410	314	330	302
VG	357	279	415	323	259	381	288	337	////	////
WS	318	264	259	210	215	235	230	215	244	244
BW	270	270	360	280	246	314	268	312	330	320
ES	266	262	390	244	260	356	274	236	258	468
HR	408	284	318	346	////	410	334	350	384	348
JHE	293	269	215	284	////	220	259	////	240	215
JR	282	314	220	242	224	258	268	248	314	308
WC	249	381	220	215	////	////	215	249	279	235
DBE	232	214	302	228	232	238	230	232	244	302
HO	448	260	////	////	434	434	////	////	////	456
IB	518	259	308	210	284	249	372	220	313	235
JHO	292	272	306	304	396	////	352	342	320	326
MBU	347	362	264	181	284	264	249	////	244	225
RT	334	264	304	234	358	316	////	352	294	366
WHS	445	352	367	396	298	293	328	372	328	////
AVG	**346**	**285**	**302**	**264**	**286**	**334**	**291**	**290**	**295**	**310**
STDEV	**104**	**61**	**56**	**63**	**64**	**116**	**54**	**59**	**46**	**77**

UT

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	533	332	308	337	279	249	342	254	235	////
HC	280	260	292	270	256	294	332	////	312	348
IG	522	328	386	368	502	368	310	302	460	320
JO	////	////	225	235	235	225	186	215	244	225
MS	280	////	////	272	244	306	270	328	258	344
VG	489	279	264	386	284	254	293	200	420	279
WS	////	240	215	230	200	215	225	220	235	244
BW	298	262	278	246	254	210	248	236	272	282
ES	308	294	234	226	216	228	252	270	262	274
HR	260	284	326	336	332	264	278	316	414	370
JHE	337	225	367	235	308	205	210	210	225	200
JR	402	250	240	272	276	246	252	254	262	////
WC	254	254	284	230	274	230	254	254	235	230
DBE	366	////	262	////	320	292	426	368	324	404
HO	344	324	290	////	322	264	////	364	448	356
IB	318	303	249	215	284	205	191	225	279	196
JHO	402	234	82	270	262	268	294	288	334	314
MBU	284	220	347	235	210	357	210	215	210	196
RT	278	240	208	308	////	244	248	364	258	324
WHS	435	288	435	357	372	367	347	411	279	425
AVG	**355**	**272**	**278**	**279**	**286**	**265**	**272**	**279**	**298**	**296**
STDEV	**90**	**36**	**77**	**55**	**68**	**52**	**61**	**64**	**78**	**71**

DN

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	264	328	284	337	284	337	264	293	////	288
HC	298	338	302	356	316	418	354	320	314	368
IG	338	468	280	216	////	348	346	////	266	344
JO	220	328	191	220	225	225	215	205	200	240
MS	428	292	298	302	428	322	358	290	358	308
VG	122	279	205	279	249	264	269	274	259	298
WS	288	240	244	264	249	259	240	244	259	////
BW	318	282	254	258	252	212	230	264	294	438
ES	294	260	234	236	254	248	330	260	282	292
HR	308	342	////	310	660	272	320	272	////	582
JHE	293	244	284	274	244	264	196	303	205	254
JR	342	246	310	344	266	274	296	358	284	436
WC	////	244	215	215	226	215	225	220	259	430
DBE	410	334	338	274	290	310	430	378	382	////
HO	342	364	////	226	204	444	326	358	196	346
IB	240	274	210	293	269	210	215	240	230	205
JHO	////	////	312	280	438	272	294	326	338	350
MBU	318	318	196	191	171	249	220	274	215	205
RT	////	270	278	270	488	320	274	444	464	290
WHS	411	415	328	288	259	249	249	386	269	303
AVG	**308**	**309**	**265**	**272**	**304**	**286**	**282**	**300**	**282**	**332**
STDEV	**74**	**61**	**47**	**45**	**119**	**64**	**62**	**62**	**70**	**94**

APPENDIX for CHAPTER 4: Establishing the min number of saccadic eye movements required for a representative result

PEAK VELOCITY (Deg/sec) 60-89 years

TEM

Number of individual runs

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	318	276	148	360	318	276	276	////	////	////
HC	282	306	319	269	319	208	342	478	282	368
IG	274	280	291	309	368	274	263	302	181	210
JO	387	////	328	298	298	298	268	328	298	298
MS	360	372	347	407	396	407	371	384	336	396
VG	507	423	451	451	451	451	451	451	479	394
WS	228	228	228	228	212	196	228	212	212	228
BW	309	318	336	327	////	309	282	291	291	309
ES	328	216	237	279	244	271	264	258	265	251
HR	383	376	383	390	419	391	362	376	391	340
JHE	292	319	319	292	////	292	292	265	292	292
JR	326	326	316	257	327	346	336	336	327	306
WC	////	198	242	286	264	286	264	264	330	220
DBE	////	643	590	591	658	537	590	573	573	417
HO	489	////	549	447	573	595	380	125	567	507
IB	393	393	372	372	372	351	351	372	372	372
JHO	306	291	321	299	284	313	277	381	374	396
MBU	237	217	198	198	198	198	178	178	178	178
RT	236	275	225	187	219	258	297	258	////	258
WHS	143	////	123	225	184	164	164	143	143	102
AVG	**322**	**321**	**316**	**324**	**339**	**321**	**312**	**314**	**327**	**307**
STDEV	**90**	**105**	**118**	**98**	**127**	**111**	**95**	**114**	**121**	**98**

UP

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	////	301	338	301	282	263	////	282	282	263
HC	268	259	304	295	304	286	259	286	340	322
IG	////	203	192	174	163	////	237	////	////	180
JO	244	298	298	298	380	380	325	298	353	298
MS	296	257	318	378	334	284	236	191	197	257
VG	286	234	286	339	312	312	325	325	312	325
WS	238	218	238	238	218	218	218	198	218	218
BW	131	156	187	181	162	149	143	175	175	175
ES	226	////	188	////	245	207	179	169	264	282
HR	343	402	355	390	385	402	373	462	420	371
JHE	323	350	323	350	377	350	377	404	350	350
JR	372	329	297	362	340	221	340	324	350	350
WC	231	243	////	231	243	243	243	255	218	291
DBE	418	369	////	402	424	385	368	379	////	462
HO	243	298	274	227	////	204	////	235	243	413
IB	272	296	247	247	222	272	272	247	222	272
JHO	285	212	298	312	289	303	285	334	289	289
MBU	294	385	340	317	317	272	272	294	362	317
RT	201	217	181	165	181	////	197	161	169	169
WHS	142	106	142	142	142	177	142	160	160	124
AVG	**267**	**270**	**267**	**281**	**280**	**274**	**266**	**273**	**274**	**286**
STDEV	**72**	**78**	**65**	**80**	**84**	**73**	**75**	**87**	**78**	**85**

NAS

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	////	350	309	////	309	309	288	185	268	268
HC	347	275	259	335	204	325	292	270	363	204
IG	377	361	306	314	314	330	////	236	307	330
JO	384	432	432	480	432	336	384	384	336	384
MS	375	376	375	394	413	394	413	393	432	394
VG	436	403	403	436	436	503	503	470	470	403
WS	327	327	294	294	294	261	261	294	294	261
BW	508	441	470	374	605	432	413	431	////	394
ES	310	304	292	256	310	304	274	268	262	245
HR	376	369	376	355	402	342	362	327	341	429
JHE	354	386	386	354	////	354	354	321	321	354
JR	277	259	250	259	224	224	259	232	241	232
WC	376	295	242	242	269	215	242	242	215	188
DBE	367	309	338	415	416	415	367	415	435	387
HO	399	////	387	465	////	417	447	447	423	322
IB	263	319	281	281	263	300	244	263	300	281
JHO	219	244	194	260	218	269	244	194	194	210
MBU	283	333	267	267	250	300	267	250	217	250
RT	234	266	250	226	////	233	////	338	346	282
WHS	367	367	////	302	367	345	367	367	389	345
AVG	**346**	**338**	**322**	**332**	**337**	**330**	**332**	**316**	**324**	**308**
STDEV	**71**	**57**	**74**	**78**	**104**	**75**	**79**	**86**	**81**	**75**

DOWN

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	284	299	268	299	331	315	221	284	252	315
HC	283	252	303	287	264	315	295	275	275	314
IG	224	224	150	114	63	////	137	192	220	228
JO	298	336	242	242	242	261	224	261	261	261
MS	347	347	321	325	389	303	318	385	302	419
VG	271	271	258	245	271	232	258	219	219	219
WS	338	318	219	239	199	239	278	////	278	239
BW	237	246	280	261	376	251	256	251	242	251
ES	226	251	318	268	235	242	277	268	251	201
HR	////	292	313	313	333	313	398	301	350	358
JHE	293	////	269	147	220	244	318	////	318	318
JR	525	421	363	379	442	534	533	446	549	488
WC	348	303	281	281	292	292	258	270	270	236
DBE	297	251	288	246	260	549	218	307	205	595
HO	313	230	293	////	188	188	216	209	188	202
IB	362	319	383	340	191	255	191	255	////	255
JHO	265	265	250	227	242	258	292	////	////	269
MBU	222	255	244	310	211	177	244	266	222	244
RT	117	189	136	95	186	107	110	57	60	57
WHS	281	328	351	328	328	258	351	351	304	304
AVG	**291**	**284**	**276**	**260**	**263**	**281**	**270**	**270**	**265**	**289**
STDEV	**81**	**54**	**62**	**75**	**87**	**105**	**91**	**84**	**95**	**114**

UN

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	////	237	237	260	213	213	189	260	213	166
HC	361	458	396	396	378	344	467	370	////	378
IG	190	230	230	209	240	219	190	180	190	130
JO	226	311	311	254	282	339	311	282	282	311
MS	199	199	190	208	226	217	235	199	234	217
VG	285	346	285	346	407	387	367	346	387	326
WS	314	314	314	279	314	349	314	244	279	244
BW	572	444	459	512	512	482	573	422	437	452
ES	348	398	////	282	348	348	480	415	299	249
HR	274	280	280	280	274	268	262	256	297	274
JHE	////	253	316	316	316	316	284	316	284	253
JR	351	282	283	222	282	291	308	325	317	317
WC	384	288	448	432	320	////	288	384	////	////
DBE	312	282	343	328	332	282	328	338	////	313
HO	////	304	////	316	304	310	257	304	290	251
IB	330	293	366	330	293	330	293	330	366	257
JHO	219	198	198	209	198	188	209	198	177	////
MBU	185	309	267	267	350	329	288	391	350	309
RT	117	135	140	135	117	94	99	123	99	////
WHS	173	173	202	231	231	144	231	260	202	202
AVG	285	287	292	291	297	287	299	297	277	273
STDEV	107	81	87	88	85	87	111	84	85	77

UT

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	412	412	300	375	337	375	337	300	375	////
HC	472	521	590	541	522	601	482	////	433	542
IG	372	390	280	326	236	308	308	290	308	352
JO	////	////	313	34	313	313	313	292	250	313
MS	329	////	////	380	360	367	380	323	405	228
VG	568	568	464	774	619	516	619	413	722	877
WS	////	230	161	230	184	184	184	184	207	161
BW	769	654	738	665	716	779	809	769	738	696
ES	537	467	583	700	676	490	560	514	491	420
HR	609	593	641	496	640	496	384	480	416	529
JHE	347	421	372	372	347	396	396	396	421	396
JR	234	234	275	275	268	303	282	309	289	////
WC	274	335	274	244	274	244	274	274	244	305
DBE	581	////	659	////	338	494	649	630	446	455
HO	361	361	351	////	351	331	////	166	361	371
IB	333	333	333	355	337	355	310	333	377	333
JHO	245	307	409	276	255	317	256	235	297	266
MBU	314	251	251	251	293	293	293	251	209	251
RT	311	226	236	139	/////	151	161	140	193	129
WHS	244	224	204	183	244	204	224	183	224	163
AVG	406	384	391	368	385	376	380	341	370	377
STDEV	151	138	171	199	163	152	171	163	152	192

DT

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	281	259	////	216	////	151	194	238	238	////
HC	433	314	284	366	623	526	598	346	480	392
IG	135	128	156	99	71	78	99	128	163	////
JO	266	266	363	291	266	291	339	266	218	////
MS	448	516	460	397	477	454	329	471	386	426
VG	246	246	192	192	246	274	246	192	////	////
WS	261	209	209	244	244	244	244	227	244	244
BW	457	503	444	400	367	309	309	271	303	290
ES	325	233	302	372	279	279	349	326	326	303
HR	359	359	300	306	////	280	313	300	273	478
JHE	235	288	235	288	////	235	235	////	261	261
JR	299	269	263	281	250	263	232	250	299	226
WC	331	362	299	284	////	/////	236	189	252	299
DBE	492	288	344	365	365	330	274	344	457	359
HO	269	213	////	////	119	176	////	////	////	295
IB	325	434	298	325	379	352	379	325	325	298
JHO	278	247	201	216	201	////	170	216	139	201
MBU	320	283	264	339	320	264	283	////	264	264
RT	79	151	107	100	101	215	////	86	187	100
WHS	120	120	105	150	135	135	105	135	135	////
AVG	298	284	268	275	278	270	274	253	275	296
STDEV	109	108	99	93	145	107	112	95	97	93

DN

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	186	167	241	223	241	223	167	282	////	278
HC	285	293	187	190	164	107	229	91	225	210
IG	78	143	84	72	////	100	84	////	56	100
JO	371	371	371	371	318	292	292	318	292	239
MS	256	268	203	197	209	221	226	203	173	322
VG	674	225	225	225	210	239	225	225	254	210
WS	311	255	227	142	198	255	255	198	255	/////
BW	349	349	371	377	343	387	316	404	256	322
ES	214	196	179	196	196	214	214	232	196	179
HR	271	277	////	291	284	297	317	311	////	317
JHE	303	303	248	303	358	330	303	303	330	303
JR	332	274	287	261	202	228	254	261	248	222
WC	////	285	256	228	199	199	199	199	142	171
DBE	298	256	347	311	305	219	329	250	303	////
HO	360	337	////	269	247	326	326	326	247	225
IB	459	459	459	434	408	408	383	383	408	383
JHO	////	////	122	139	134	140	128	116	105	104
MBU	273	213	304	273	243	273	273	213	304	273
RT	////	175	115	157	127	91	115	97	79	163
WHS	336	268	336	313	291	313	313	268	268	358
AVG	315	269	253	248	246	243	247	246	230	243
STDEV	125	77	100	90	77	89	80	87	91	82

APPENDIX for CHAPTER 4: Establishing the min number of saccadic eye movements required for a representative result

AMPLITUDE (Degrees) 60-89 years

TEM — Number of individual runs

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	8.18	7.35	6.21	9.53	8.49	7.14	7.56	////	////	////
HC	10.90	16.99	14.72	9.04	14.37	12.98	12.27	19.03	13.15	16.73
IG	8.97	9.22	8.23	9.65	9.53	8.53	8.42	8.00	8.10	8.07
JO	11.06	////	8.15	8.29	8.15	8.29	7.71	8.15	7.71	8.01
MS	8.72	9.11	8.68	10.57	10.33	9.49	9.97	9.44	8.89	9.85
VG	13.21	14.58	15.41	18.02	10.59	13.48	14.72	15.54	13.89	12.38
WS	6.69	6.84	7.00	6.45	6.21	6.21	6.76	5.89	6.29	6.13
BW	9.27	9.43	7.96	8.36	////	7.47	7.25	7.58	7.27	7.25
ES	10.79	8.57	8.18	10.03	9.53	8.29	8.85	8.71	9.32	9.64
HR	10.76	10.74	10.71	10.83	10.54	10.97	10.19	10.57	11.09	10.77
JHE	7.65	8.68	7.78	7.52	////	7.78	8.17	6.74	7.91	6.74
JR	11.73	9.91	9.95	10.72	11.23	10.94	10.42	10.09	10.76	12.70
WC	////	6.67	7.74	8.71	8.06	7.96	7.53	9.57	8.60	7.42
DBE	////	14.40	13.15	12.36	14.47	12.08	13.61	13.33	12.81	10.00
HO	10.71	////	11.27	10.02	10.59	11.78	8.09	9.65	11.46	10.66
IB	11.60	11.30	11.00	10.80	10.90	10.59	10.39	9.38	9.48	10.49
JHO	11.82	11.33	11.37	11.52	12.28	11.60	12.18	12.66	13.18	13.39
MBU	8.88	9.26	8.49	8.23	8.40	8.30	7.53	6.56	6.47	6.95
RT	8.24	8.75	7.28	5.19	9.03	11.36	10.79	10.21	////	9.20
WHS	4.70	////	3.70	7.40	5.30	5.40	5.30	5.70	4.90	3.50
AVG	**9.66**	**10.18**	**9.35**	**9.66**	**9.89**	**9.53**	**9.38**	**9.83**	**9.52**	**9.47**
STDEV	**2.12**	**2.83**	**2.87**	**2.64**	**2.39**	**2.31**	**2.44**	**3.37**	**2.65**	**3.03**

NAS

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	/////	8.64	9.35	////	9.35	9.05	8.95	9.55	8.24	7.94
HC	12.15	13.65	14.49	10.68	10.95	10.83	11.38	14.18	10.62	8.27
IG	12.36	9.69	9.06	12.00	9.16	8.62	////	9.69	10.58	10.71
JO	10.31	9.61	11.03	11.01	10.78	11.25	11.01	9.84	10.55	10.55
MS	10.10	10.10	10.25	10.58	11.00	10.47	10.77	10.36	10.40	10.66
VG	12.78	12.29	12.29	11.96	12.29	14.58	12.45	13.76	13.43	13.27
WS	9.73	9.73	9.73	9.09	9.41	9.09	9.25	9.89	9.41	9.57
BW	11.38	9.19	10.49	10.03	15.12	10.05	9.55	12.05	////	8.86
ES	8.77	8.48	9.53	8.38	10.61	9.08	9.35	8.11	8.27	8.48
HR	9.67	9.90	10.19	9.40	10.15	9.88	10.18	9.62	9.36	10.28
JHE	9.89	9.57	10.83	10.04	////	10.36	9.57	9.42	9.26	9.73
JR	9.94	9.44	9.10	8.71	8.35	7.69	8.42	7.49	7.46	9.83
WC	11.80	10.88	9.70	8.92	9.18	9.57	9.31	7.87	8.00	7.87
DBE	10.34	8.91	10.32	10.82	10.80	10.35	10.26	10.99	10.12	9.85
HO	8.12	////	8.39	10.18	////	8.81	11.49	12.05	11.05	8.99
IB	9.07	10.71	10.16	8.70	8.88	9.34	9.25	7.97	9.80	8.88
JHO	8.41	7.69	7.72	7.84	8.21	8.24	7.42	8.23	7.42	7.37
MBU	10.17	10.17	10.09	9.92	8.54	11.31	9.92	10.25	8.62	9.03
RT	8.08	10.23	6.62	8.33	////	11.31	////	11.72	11.61	9.24
WHS	11.49	11.18	////	10.97	10.97	11.18	10.97	10.54	11.28	10.44
AVG	**10.24**	**10.00**	**9.96**	**9.87**	**10.22**	**10.05**	**9.97**	**10.18**	**9.76**	**9.49**
STDEV	**1.43**	**1.36**	**1.66**	**1.22**	**1.71**	**1.51**	**1.22**	**1.87**	**1.56**	**1.33**

UP

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	////	9.63	10.36	9.08	8.35	9.63	////	10.46	11.56	9.90
HC	11.68	12.04	10.91	14.43	14.04	14.68	13.88	13.15	14.99	13.15
IG	////	10.70	8.93	12.51	10.54	////	13.78	////	////	10.42
JO	5.69	6.49	6.62	7.81	11.52	12.32	10.33	8.48	10.73	10.99
MS	7.10	7.32	7.08	6.93	7.53	5.75	4.47	4.31	4.94	5.35
VG	7.44	8.14	7.82	9.41	8.90	9.73	9.22	9.28	8.96	8.39
WS	8.23	8.62	9.10	9.59	8.91	9.39	8.52	8.62	8.62	8.13
BW	10.88	10.82	11.14	10.12	11.05	10.27	8.51	11.94	10.24	10.85
ES	11.89	////	7.16	////	10.44	6.95	6.05	6.39	8.85	12.68
HR	8.53	11.57	11.53	11.11	10.83	11.26	9.60	11.23	12.73	11.37
JHE	9.73	11.31	9.73	10.79	10.39	9.47	11.05	10.52	9.34	10.26
JR	11.68	11.92	12.18	12.45	11.75	11.90	12.09	12.90	12.04	12.58
WC	8.00	7.64	////	7.35	8.06	8.35	7.23	7.70	7.88	8.00
DBE	11.11	14.03	////	13.10	13.19	12.94	9.13	13.03	////	12.55
HO	10.05	9.96	6.51	8.58	////	10.27	////	9.42	9.33	8.20
IB	9.64	10.61	10.00	8.80	7.95	10.12	8.20	9.52	8.08	9.04
JHO	10.53	9.08	10.14	9.29	10.52	10.25	10.16	9.81	8.72	9.71
MBU	11.39	12.27	11.83	11.72	11.94	10.72	10.83	11.83	13.04	11.39
RT	11.11	10.10	11.74	10.71	10.82	////	10.18	10.87	11.39	10.93
WHS	4.76	7.62	6.58	3.55	6.75	4.94	6.58	4.76	5.98	4.94
AVG	**9.41**	**9.99**	**9.41**	**9.86**	**10.18**	**9.94**	**9.43**	**9.70**	**9.86**	**9.94**
STDEV	**2.15**	**2.00**	**2.00**	**2.52**	**1.95**	**2.41**	**2.48**	**2.57**	**2.51**	**2.28**

DOWN

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	7.85	8.15	7.15	10.92	9.38	8.54	8.62	9.08	8.23	10.31
HC	7.68	7.01	8.83	8.77	8.05	9.13	9.17	10.22	7.86	9.10
IG	7.24	10.25	8.74	9.36	7.40	////	8.73	8.59	11.02	8.07
JO	6.56	7.10	6.74	6.83	6.56	6.74	6.65	6.92	6.46	6.92
MS	10.41	9.16	9.49	9.84	10.02	9.47	9.79	9.91	10.47	9.65
VG	8.13	8.38	8.19	7.31	7.94	7.25	6.99	6.68	6.43	7.94
WS	11.07	9.61	9.22	9.42	9.03	7.28	9.42	////	9.03	9.12
BW	6.87	7.43	8.64	8.23	9.77	7.51	8.03	9.41	7.37	6.24
ES	6.50	8.42	10.32	8.04	8.42	9.39	10.23	8.57	8.61	7.22
HR	////	7.99	7.79	8.55	7.29	9.30	8.79	10.77	10.42	9.40
JHE	5.85	////	7.28	5.01	5.61	5.49	7.28	////	7.88	8.47
JR	10.74	10.86	10.58	10.37	9.89	9.67	9.31	9.67	9.19	9.30
WC	9.44	9.88	8.83	9.93	9.77	9.77	9.60	9.11	9.38	8.61
DBE	6.85	7.05	6.31	5.84	7.14	10.01	5.86	6.63	5.80	10.62
HO	7.05	5.82	8.84	////	5.37	7.42	6.50	8.86	5.68	7.45
IB	7.90	7.17	7.48	7.27	5.92	7.06	6.44	5.82	////	7.69
JHO	8.79	8.58	8.31	8.75	9.39	9.32	8.83	////	////	7.11
MBU	6.55	8.77	7.42	8.07	8.23	6.55	8.12	9.09	8.17	8.17
RT	4.34	7.61	5.94	3.86	7.27	7.46	8.08	6.80	6.13	5.55
WHS	7.20	9.72	10.98	9.61	10.29	9.15	11.09	12.01	9.72	10.06
AVG	**7.74**	**8.37**	**8.35**	**8.21**	**8.14**	**8.24**	**8.38**	**8.71**	**8.21**	**8.35**
STDEV	**1.72**	**1.31**	**1.37**	**1.85**	**1.54**	**1.34**	**1.40**	**1.67**	**1.66**	**1.37**

UN

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	////	7.86	7.05	7.97	7.40	7.68	6.59	8.55	7.86	6.93
HC	9.94	13.78	10.31	12.54	10.75	10.04	9.11	11.35	////	10.59
IG	8.29	11.44	10.48	11.10	8.67	9.29	9.89	8.09	9.11	8.33
JO	8.55	13.10	15.03	13.79	13.79	13.38	16.00	13.10	13.66	14.35
MS	7.35	9.81	10.93	10.98	11.78	12.10	10.95	11.09	11.65	11.88
VG	9.85	13.33	12.13	12.73	14.42	14.82	14.82	12.73	14.22	11.93
WS	9.87	10.72	10.55	10.89	10.55	10.04	11.06	10.72	10.21	10.89
BW	13.50	11.72	10.99	11.87	12.44	11.88	11.84	10.95	10.33	9.97
ES	8.75	10.44	////	8.55	9.61	9.15	9.61	9.88	10.48	10.14
HR	9.21	10.31	10.99	11.54	11.04	8.53	9.57	10.60	10.13	10.55
JHE	////	10.02	13.41	13.26	13.88	14.80	12.95	12.80	10.95	9.10
JR	10.04	10.30	9.72	7.12	10.35	9.19	9.49	10.57	9.34	10.37
WC	13.05	10.00	13.52	13.44	12.19	////	11.49	13.13	////	////
DBE	7.95	8.11	8.40	9.18	8.25	7.31	9.39	8.59	////	7.29
HO	////	9.87	////	8.49	9.53	10.23	9.40	9.17	7.73	9.28
IB	9.48	11.45	10.74	9.31	8.41	9.66	9.31	10.56	9.84	9.84
JHO	10.35	12.04	13.09	10.92	11.48	9.54	10.06	9.12	9.39	////
MBU	10.04	13.46	14.26	13.66	15.37	14.46	15.57	16.47	15.97	16.17
RT	5.83	7.85	10.18	8.33	7.51	7.71	8.20	9.36	7.58	////
WHS	14.65	9.44	12.12	13.39	12.12	10.85	14.09	13.95	15.08	15.22
AVG	**9.81**	**10.75**	**11.33**	**10.95**	**10.98**	**10.56**	**10.97**	**11.04**	**10.80**	**10.75**
STDEV	**1.90**	**1.81**	**2.08**	**2.13**	**2.36**	**2.46**	**2.49**	**2.06**	**2.36**	**2.35**

UT

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	10.80	9.88	7.14	9.15	8.24	8.60	7.69	8.60	7.69	////
HC	14.19	14.66	16.43	17.49	14.44	16.16	14.03	////	15.39	17.26
IG	11.36	12.38	9.68	10.39	9.15	9.55	9.80	8.95	9.71	10.29
JO	////	////	8.76	10.49	8.86	8.96	8.86	8.25	8.35	8.86
MS	7.33	////	////	7.74	7.42	7.67	7.35	8.00	7.97	6.05
VG	16.88	17.13	16.38	24.44	17.64	15.87	17.38	13.35	18.89	////
WS	////	8.86	8.98	8.30	7.29	7.63	8.53	7.85	8.53	6.96
BW	14.56	13.17	13.67	12.71	13.48	13.69	14.75	12.65	12.74	13.61
ES	14.37	10.64	13.16	14.23	12.69	12.97	10.59	9.38	9.47	9.52
HR	14.06	13.00	13.13	13.16	14.41	11.59	11.18	11.21	11.75	11.78
JHE	8.59	12.70	9.68	9.68	9.92	10.52	10.40	10.04	10.28	9.92
JR	9.40	9.47	9.87	9.36	9.70	9.63	8.92	10.84	10.82	////
WC	8.48	11.75	10.12	8.93	10.12	8.33	10.41	10.27	8.18	9.08
DBE	12.53	////	11.87	////	8.21	12.43	14.80	13.42	11.70	11.33
HO	11.68	12.01	10.63	////	10.30	10.57	////	7.98	9.03	13.03
IB	9.85	9.64	9.31	9.64	9.64	10.18	9.31	10.18	9.53	9.31
JHO	11.77	11.75	14.23	12.24	11.85	13.61	11.38	10.89	11.77	10.40
MBU	12.58	10.74	9.72	10.02	10.95	10.84	10.43	9.72	8.69	10.02
RT	13.81	9.62	10.33	7.26	////	8.91	9.62	9.17	8.94	8.72
WHS	8.75	9.05	8.16	9.45	8.85	7.66	9.25	7.36	9.05	7.06
AVG	**11.72**	**11.56**	**11.12**	**11.37**	**10.69**	**10.77**	**10.77**	**9.90**	**10.42**	**10.19**
STDEV	**2.63**	**2.20**	**2.67**	**4.13**	**2.75**	**2.61**	**2.66**	**1.82**	**2.76**	**2.71**

DT

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	7.17	6.96	////	6.12	////	7.17	5.38	7.38	6.75	////
HC	14.20	9.56	6.80	8.06	9.35	9.11	8.28	7.44	10.24	9.53
IG	5.93	6.07	6.64	5.73	5.52	7.83	5.25	6.61	5.07	////
JO	6.74	7.69	7.33	7.09	7.09	8.28	7.69	6.50	5.56	////
MS	10.10	10.57	9.96	9.94	10.86	10.59	9.45	11.01	10.62	10.27
VG	7.89	6.15	4.68	5.35	7.22	7.75	6.82	5.88	////	////
WS	7.15	6.55	7.83	7.06	7.24	7.15	8.60	7.32	6.89	7.24
BW	12.06	11.50	12.14	11.50	8.76	9.79	8.05	13.15	7.91	8.12
ES	9.07	8.84	8.10	8.10	9.59	9.12	9.03	8.93	8.00	8.24
HR	10.38	9.13	9.40	8.62	////	8.37	9.14	7.90	8.12	12.85
JHE	6.89	7.92	6.13	6.13	////	8.04	6.51	////	7.40	6.26
JR	10.12	8.47	8.76	8.33	7.59	8.73	7.17	8.64	9.79	7.97
WC	10.00	11.00	10.77	10.54	////	////	7.69	6.23	8.00	8.62
DBE	6.90	6.64	6.88	7.47	7.99	7.78	7.10	6.96	8.49	8.52
HO	8.09	6.11	////	////	6.31	7.52	////	////	////	8.05
IB	9.39	11.25	8.86	8.34	9.39	10.85	9.79	8.47	8.86	7.14
JHO	7.13	6.33	6.36	7.34	5.86	////	6.79	7.75	6.14	5.34
MBU	10.21	8.83	11.13	12.24	9.94	10.03	10.12	////	10.58	10.67
RT	5.49	7.96	6.87	6.10	6.70	6.74	////	7.43	7.57	6.50
WHS	3.22	4.54	3.52	4.03	3.44	4.91	3.74	4.76	5.42	////
AVG	**8.41**	**8.10**	**7.90**	**7.79**	**7.68**	**8.32**	**7.59**	**7.79**	**7.86**	**8.35**
STDEV	**2.49**	**1.98**	**2.24**	**2.12**	**1.92**	**1.46**	**1.70**	**1.96**	**1.72**	**1.90**

DN

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	4.71	5.35	6.43	6.61	6.43	6.61	4.80	5.44	////	7.33
HC	6.53	7.04	6.77	5.96	6.21	4.26	5.39	5.14	4.95	4.50
IG	11.43	9.74	10.51	8.11	////	10.16	8.52	////	7.22	8.61
JO	9.84	9.06	9.06	8.93	8.80	8.67	8.16	8.28	8.41	7.77
MS	7.21	7.53	6.14	6.97	6.92	6.53	5.82	7.31	8.19	6.91
VG	10.60	6.07	6.07	7.31	6.07	6.65	6.94	6.43	7.60	6.36
WS	8.99	10.51	9.13	8.71	8.57	9.26	9.13	9.40	9.40	////
BW	9.48	9.06	9.44	10.25	9.22	11.24	9.32	11.45	7.91	9.31
ES	5.96	6.03	4.60	6.21	5.92	6.42	6.88	6.81	6.28	6.10
HR	6.26	6.67	////	7.40	6.82	7.11	8.26	7.86	////	7.21
JHE	7.39	6.58	6.31	7.52	7.66	6.45	7.93	7.12	7.93	7.66
JR	7.64	8.83	6.05	6.42	7.51	5.71	6.96	6.74	8.23	5.97
WC	////	9.45	8.20	7.50	8.20	7.50	7.64	6.53	5.28	7.36
DBE	5.20	5.91	7.22	5.94	7.04	5.08	6.88	5.91	5.91	////
HO	7.68	7.01	////	6.76	6.07	7.91	7.28	8.04	6.27	7.39
IB	11.09	12.34	10.84	10.59	10.34	10.72	10.47	9.97	10.09	10.34
JHO	////	////	4.41	3.73	5.35	3.92	3.24	3.37	3.73	3.65
MBU	6.82	7.42	8.75	7.86	8.75	7.86	8.31	8.31	9.49	9.35
RT	////	6.88	6.86	5.29	4.96	5.52	6.38	7.91	4.32	9.41
WHS	9.39	9.29	11.03	10.38	8.63	9.29	10.60	9.72	9.94	10.16
AVG	**8.01**	**7.93**	**7.66**	**7.42**	**7.34**	**7.34**	**7.44**	**7.46**	**7.29**	**7.52**
STDEV	**2.05**	**1.85**	**2.04**	**1.74**	**1.46**	**2.05**	**1.81**	**1.90**	**1.93**	**1.83**

APPENDIX for CHAPTER 4: Establishing the min number of saccadic eye movements required for a representative result

DURATION (msecs) 60-89 years

TEM

Number of individual runs

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	39	44	59	44	44	44	49	////	////	////
HC	66	92	80	48	92	124	72	86	74	76
IG	64	66	58	64	64	56	60	54	100	64
JO	49	////	39	39	39	39	39	39	39	39
MS	40	40	46	44	44	36	38	36	42	46
VG	44	49	44	78	29	44	44	49	44	44
WS	44	44	44	39	44	44	44	44	44	44
BW	50	50	46	44	////	40	50	52	52	42
ES	58	62	60	80	64	60	64	56	58	60
HR	52	52	54	48	46	50	48	48	54	48
JHE	39	44	39	39	////	44	44	39	44	39
JR	58	50	50	76	52	52	50	50	52	74
WC	////	44	54	49	49	44	49	64	49	49
DBE	////	40	40	38	40	40	42	42	38	42
HO	52	////	48	48	46	50	44	118	42	46
IB	49	44	49	44	49	44	49	39	44	44
JHO	56	60	60	62	66	60	62	56	62	64
MBU	64	64	64	64	68	68	64	59	64	64
RT	56	62	56	52	68	70	68	64	////	66
WHS	73	////	59	88	59	64	68	78	64	59
AVG	**53**	**53**	**52**	**54**	**54**	**54**	**52**	**56**	**54**	**53**
STDEV	**10**	**13**	**10**	**16**	**15**	**19**	**11**	**20**	**15**	**12**

NAS

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	////	39	49	////	49	44	44	78	49	49
HC	64	96	98	74	118	62	74	150	54	80
IG	66	50	50	68	52	46	////	66	54	66
JO	59	44	49	44	39	49	54	39	49	44
MS	42	46	46	44	46	48	50	44	50	42
VG	39	39	39	39	59	44	59	44	39	44
WS	49	49	54	49	59	54	49	64	49	59
BW	48	50	42	50	84	44	42	48	////	40
ES	46	48	50	50	56	56	58	50	50	52
HR	46	42	46	50	50	46	46	44	48	50
JHE	44	54	49	49	////	54	49	54	44	54
JR	54	54	58	60	56	54	56	52	52	66
WC	49	54	54	59	49	59	59	49	54	59
DBE	50	42	44	42	44	42	44	40	42	42
HO	38	////	40	42	////	38	42	40	44	58
IB	44	44	49	44	49	44	54	44	49	44
JHO	148	78	128	108	190	178	98	////	104	94
MBU	54	54	54	59	49	54	59	59	59	54
RT	70	62	48	58	////	82	////	66	68	58
WHS	64	59	////	54	44	78	54	54	64	37
AVG	**56**	**53**	**55**	**55**	**64**	**59**	**55**	**57**	**54**	**55**
STDEV	**24**	**14**	**22**	**16**	**37**	**30**	**13**	**25**	**14**	**14**

UP

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	////	49	54	59	49	73	////	78	73	83
HC	104	130	84	112	116	158	140	126	90	84
IG	////	126	86	138	114	////	140	////	////	180
JO	34	39	34	49	54	59	54	39	54	59
MS	64	72	40	38	76	44	44	44	130	54
VG	44	54	44	44	49	44	44	44	49	44
WS	54	59	54	64	64	68	64	68	59	59
BW	////	////	////	////	////	////	////	////	////	////
ES	////	////	172	////	////	92	100	100	126	168
HR	46	62	68	58	60	66	48	50	66	58
JHE	54	54	49	54	44	39	44	44	39	49
JR	96	98	106	108	128	114	100	96	90	98
WC	49	49	////	49	54	54	44	49	59	49
DBE	58	100	////	100	82	114	44	114	////	72
HO	146	120	50	160	////	////	////	104	114	48
IB	64	83	83	68	64	83	49	73	64	64
JHO	72	76	74	62	100	86	94	82	70	76
MBU	103	103	78	103	93	88	103	108	117	103
RT	150	88	170	132	110	////	104	158	166	206
WHS	54	88	78	44	73	49	73	54	64	59
AVG	**74**	**80**	**78**	**80**	**78**	**77**	**76**	**80**	**84**	**85**
STDEV	**35**	**28**	**40**	**37**	**27**	**32**	**34**	**34**	**35**	**48**

DOWN

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	39	44	44	59	44	44	64	49	49	49
HC	52	50	56	56	48	52	52	58	46	60
IG	////	104	196	////	////	////	152	148	108	94
JO	34	44	44	44	44	44	44	39	39	44
MS	70	60	52	66	48	52	50	52	70	46
VG	49	54	49	49	49	59	49	49	44	64
WS	54	54	98	73	98	59	59	////	73	59
BW	50	54	56	60	50	54	54	84	52	44
ES	50	56	58	58	60	56	70	58	60	62
HR	////	64	54	74	50	58	66	78	80	60
JHE	39	////	39	49	39	29	39	////	39	44
JR	48	56	66	60	66	52	46	66	58	68
WC	34	44	44	49	44	44	49	49	49	49
DBE	50	58	44	42	56	44	48	46	54	80
HO	56	54	78	////	62	64	52	76	52	64
IB	44	68	49	49	59	54	73	49	////	54
JHO	78	66	64	80	60	60	68	////	////	52
MBU	49	68	59	49	83	59	64	64	59	59
RT	90	78	112	106	88	188	164	224	200	164
WHS	73	64	73	54	83	68	73	68	103	64
AVG	**53**	**60**	**67**	**60**	**60**	**60**	**67**	**74**	**69**	**64**
STDEV	**15**	**14**	**36**	**16**	**17**	**32**	**33**	**46**	**38**	**27**

UN

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	////	49	49	49	49	54	54	59	64	68
HC	52	56	42	58	48	44	46	48	////	48
IG	70	96	100	160	76	112	178	96	108	148
JO	68	93	103	103	98	93	108	98	103	103
MS	144	150	////	176	////	////	////	////	////	////
VG	59	78	93	88	93	93	98	83	93	78
WS	64	64	59	88	73	54	68	68	68	78
BW	52	52	54	50	62	50	50	58	52	48
ES	58	92	////	74	74	82	64	58	82	96
HR	108	82	184	176	122	64	100	98	96	98
JHE	////	68	112	83	88	112	88	88	78	54
JR	72	58	62	52	68	60	68	64	56	60
WC	49	49	64	49	58	////	59	54	////	////
DBE	46	46	48	50	48	42	76	54	////	46
HO	////	74	////	58	48	78	74	72	40	86
IB	39	68	68	54	54	59	78	54	54	59
JHO	124	134	130	142	144	146	144	194	120	////
MBU	127	108	132	108	122	122	132	137	132	132
RT	136	112	160	150	126	172	134	150	148	////
WHS	////	108	117	122	132	122	132	127	161	152
AVG	**79**	**82**	**93**	**94**	**83**	**87**	**92**	**87**	**91**	**85**
STDEV	**36**	**29**	**42**	**45**	**32**	**38**	**37**	**40**	**36**	**35**

UT

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	39	44	44	39	44	44	34	59	39	////
HC	58	60	66	74	62	68	66	////	76	74
IG	58	60	68	68	86	58	56	60	60	56
JO	////	////	49	59	49	54	54	49	54	49
MS	38	////	////	34	34	36	38	36	32	38
VG	44	49	73	73	44	64	44	49	44	49
WS	////	64	137	68	64	78	78	78	78	68
BW	50	46	48	42	48	40	38	42	40	44
ES	50	46	40	44	34	42	36	42	40	40
HR	54	50	52	46	48	46	54	38	40	44
JHE	44	44	39	44	44	44	44	44	44	44
JR	80	86	86	112	106	80	80	82	96	////
WC	49	68	83	59	83	59	78	88	59	59
DBE	42	////	44	////	42	50	42	38	50	40
HO	68	96	90	////	82	94	////	186	66	102
IB	44	49	44	44	39	49	44	49	39	44
JHO	82	78	100	78	92	88	84	84	96	68
MBU	68	68	64	68	59	68	59	68	83	73
RT	116	138	116	164	////	158	132	120	106	102
WHS	59	78	73	98	78	78	93	78	78	73
AVG	**58**	**66**	**69**	**67**	**60**	**65**	**61**	**68**	**61**	**59**
STDEV	**19**	**24**	**27**	**32**	**22**	**28**	**25**	**36**	**23**	**20**

DT

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	34	34	////	44	////	73	34	49	44	////
HC	70	50	40	42	44	38	32	50	60	52
IG	66	76	84	106	122	154	80	84	54	////
JO	44	39	34	34	39	54	34	34	39	////
MS	48	40	40	42	40	40	52	48	46	38
VG	44	39	39	39	49	49	49	44	////	////
WS	44	49	59	44	49	49	54	49	49	44
BW	42	46	54	54	40	58	40	82	48	46
ES	48	62	56	54	62	70	66	62	54	58
HR	54	44	50	48	////	48	48	48	46	46
JHE	44	44	39	34	////	49	44	////	44	39
JR	56	52	56	50	52	56	50	52	58	54
WC	44	44	59	54	////	////	44	44	44	44
DBE	42	40	38	42	40	40	46	42	44	42
HO	52	50	////	////	90	62	////	////	////	42
IB	44	64	39	39	44	54	39	39	49	39
JHO	46	52	54	60	52	////	68	60	68	44
MBU	54	54	68	73	54	59	54	////	59	59
RT	////	92	144	////	100	54	////	////	80	128
WHS	44	49	44	39	39	49	49	49	49	////
AVG	**48**	**51**	**55**	**50**	**57**	**59**	**49**	**52**	**52**	**52**
STDEV	**9**	**14**	**25**	**17**	**25**	**26**	**12**	**14**	**10**	**22**

DN

Sbjs	1	2	3	4	5	6	7	8	9	10
EB	39	49	44	49	44	49	44	59	////	44
HC	42	52	60	66	60	68	54	102	46	42
IG	61	35	51	31	////	////	////	////	50	////
JO	39	39	44	39	39	44	39	39	44	44
MS	44	50	50	56	54	58	46	60	70	48
VG	24	39	39	68	44	49	44	44	64	49
WS	54	88	93	108	103	68	78	117	73	////
BW	48	44	44	48	48	58	50	50	50	58
ES	52	50	48	54	50	62	56	58	54	54
HR	46	40	////	48	42	44	44	46	////	44
JHE	39	39	34	34	34	29	44	39	39	39
JR	54	70	44	52	64	60	54	46	68	46
WC	////	49	49	44	54	49	54	44	54	59
DBE	42	46	38	42	48	48	50	42	40	////
HO	40	36	////	48	44	46	38	48	46	56
IB	39	44	39	39	49	44	49	44	44	44
JHO	////	////	64	66	70	72	58	76	78	90
MBU	49	64	59	54	73	64	49	64	59	64
RT	////	88	116	96	62	138	138	60	128	108
WHS	64	64	64	59	54	54	59	78	59	73
AVG	**46**	**52**	**54**	**55**	**55**	**58**	**55**	**59**	**59**	**57**
STDEV	**9**	**16**	**21**	**19**	**16**	**22**	**22**	**21**	**21**	**19**

APPENDIX for Chapter 5

This appendix shows the data of each observer in different age groups and directions of gaze for each saccadic parameter under investigation. The values in each cell represent the average of four individual measurements. At the bottom of each column there is the average, standard deviation and standard error of the mean of each age group in that specific direction of gaze.

APPENDIX for CHAPTER 5: Effect of ageing and direction on saccadic eye movements

LATENCY (msecs) / GROUP I (20-39 years)

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AS	280	250	270	260	260	280	250	250
AR	200	200	230	250	220	210	220	200
AB	290	290	270	280	280	250	260	270
AN	220	190	190	220	210	230	220	200
AM	240	220	250	250	260	250	240	250
CH	220	230	230	260	230	240	240	240
DC	270	230	280	310	230	250	240	240
EP	200	200	230	260	210	220	200	260
EL	220	200	210	230	310	260	220	240
EG	220	220	270	210	240	210	250	220
IM	270	290	250	240	220	290	310	270
IU	220	240	220	240	220	210	220	200
KH	190	210	230	250	220	220	240	250
MB	300	280	270	290	320	370	260	310
MM	210	190	230	220	250	220	250	210
PM	220	200	230	230	200	240	230	260
PK	250	280	260	320	250	280	260	260
RS	210	210	270	290	230	260	240	230
SN	260	230	220	220	250	270	230	200
VA	230	230	250	260	240	230	230	260
AVG	**236**	**230**	**243**	**255**	**243**	**250**	**241**	**241**
STDEV	**32**	**33**	**25**	**31**	**32**	**38**	**23**	**29**
SEM	**7**	**7**	**5**	**7**	**7**	**8**	**5**	**7**

LATENCY (msecs) / GROUP II (40-59 years)

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AP	200	260	220	310	230	200	230	290
CV	210	270	240	220	250	200	220	270
DT	240	230	240	270	240	240	240	240
JB	230	230	220	220	230	240	250	220
LS	260	250	240	290	250	320	220	280
SL	200	210	200	250	220	220	200	230
SA	230	260	290	270	290	240	260	290
DB	260	220	220	240	250	230	230	250
GC	290	280	300	280	260	300	320	300
JL	220	200	220	240	260	240	240	220
LK	300	250	270	300	280	300	290	290
SHE	220	290	280	300	260	270	270	300
SH	230	250	230	260	230	230	260	270
BD	310	290	290	310	260	280	280	290
DK	280	280	290	280	310	270	300	280
GB	300	290	240	270	220	290	260	300
LB	270	290	260	320	270	280	280	270
MT	250	250	280	270	240	250	250	240
SF	230	230	250	220	230	250	230	210
TK	240	250	260	240	250	270	250	240
AVG	**249**	**254**	**252**	**268**	**252**	**256**	**254**	**264**
STDEV	**34**	**28**	**29**	**31**	**23**	**33**	**30**	**30**
SEM	**8**	**6**	**7**	**7**	**5**	**7**	**7**	**7**

LATENCY (msecs) / GROUP III (60-89 years)

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
EB	380	240	310	290	310	270	320	290
HC	240	230	230	280	240	300	250	240
IG	360	290	280	320	280	330	310	250
JO	250	250	230	240	270	260	250	250
MS	320	310	310	340	300	250	350	350
VG	310	270	320	310	430	410	340	310
WS	380	300	320	360	310	400	390	330
BW	220	210	240	270	220	250	250	260
ES	280	240	240	250	240	260	220	230
HR	270	240	250	260	250	270	250	240
JHE	290	330	310	280	330	350	370	320
JR	240	250	250	240	240	240	220	250
WC	250	260	260	290	270	300	260	270
DBE	300	280	270	280	270	290	290	340
HO	340	300	320	420	290	350	320	380
IB	270	250	270	290	290	270	270	320
JHO	340	290	280	320	290	340	290	340
MBU	210	270	260	280	290	310	270	350
RT	270	300	300	300	290	300	260	280
WHS	340	300	290	330	280	320	270	330
AVG	**293**	**271**	**277**	**298**	**285**	**304**	**288**	**297**
STDEV	**52**	**32**	**31**	**43**	**44**	**48**	**48**	**46**
SEM	**12**	**7**	**7**	**10**	**10**	**11**	**11**	**10**

PEAK VELOCITY (Deg/sec) / GROUP I (20-39 years)

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AS	425	297	332	316	516	251	327	263
AR	328	423	223	333	270	387	398	353
AB	391	251	148	411	262	293	360	303
AN	562	257	203	310	262	318	436	366
AM	620	330	387	269	189	317	321	216
CH	565	232	348	312	341	276	572	333
DC	492	361	329	218	341	344	435	406
EP	614	300	225	322	210	382	308	348
EL	486	288	213	227	148	407	261	160
EG	288	276	203	226	287	304	240	281
IM	478	387	200	265	368	327	252	285
IU	327	184	183	278	235	260	327	234
KH	320	414	310	382	437	321	381	401
MB	196	320	340	239	280	322	387	231
MM	201	328	283	240	245	354	353	346
PM	186	321	277	237	317	227	273	360
PK	234	235	439	258	267	225	266	249
RS	583	309	168	259	183	300	287	200
SN	392	349	284	383	196	241	315	365
VA	519	497	343	224	429	484	410	263
AVG	**410**	**318**	**272**	**285**	**289**	**317**	**345**	**298**
STDEV	**145**	**74**	**80**	**58**	**94**	**65**	**81**	**70**
SEM	**32**	**17**	**18**	**13**	**21**	**15**	**18**	**16**

PEAK VELOCITY (Deg/sec) / GROUP III (60-89 years)

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
EB	282	286	289	287	221	225	358	221
HC	372	279	257	284	319	344	340	423
IG	451	446	306	246	348	229	614	271
JO	262	252	244	283	364	282	274	209
MS	575	386	401	322	317	362	531	291
VG	470	414	267	225	292	215	332	296
WS	275	319	191	180	201	118	317	90
BW	295	354	356	266	295	255	386	308
ES	311	398	317	263	291	285	268	323
HR	196	268	317	239	304	289	266	264
JHE	155	357	144	318	205	127	210	407
JR	220	291	222	261	296	237	192	233
WC	261	283	220	254	352	310	544	202
DBE	377	396	275	346	212	436	347	228
HO	381	368	390	330	275	330	528	296
IB	320	246	329	468	298	263	274	257
JHO	317	287	292	286	394	436	523	198
MBU	246	272	180	111	118	131	172	118
RT	308	452	163	265	487	365	733	347
WHS	324	225	290	259	200	208	286	124
AVG	**320**	**329**	**273**	**275**	**289**	**272**	**375**	**255**
STDEV	**98**	**70**	**71**	**69**	**82**	**91**	**153**	**88**
SEM	**22**	**16**	**16**	**16**	**18**	**20**	**34**	**20**

PEAK VELOCITY (Deg/sec) / GROUP II (40-59 years)

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AP	567	444	137	305	256	324	405	246
CV	493	308	284	299	230	265	398	210
DT	322	344	280	265	310	513	271	207
JB	348	237	215	322	277	176	204	228
LS	526	397	315	179	362	187	514	223
SL	492	235	236	281	215	277	269	236
SA	389	540	267	182	402	210	380	365
DB	496	471	223	147	217	249	372	129
GC	300	303	280	315	561	251	300	193
JL	319	276	256	287	235	243	373	251
LK	348	234	270	194	327	250	382	211
SHE	398	248	270	322	358	225	483	369
SH	499	354	253	252	334	402	277	384
BD	509	271	246	273	349	347	249	294
DK	450	287	263	280	287	283	348	313
GB	582	356	306	358	290	364	800	344
LB	757	258	234	269	253	299	483	206
MT	480	299	367	391	456	284	766	269
SF	448	373	307	262	256	231	252	184
TK	595	462	352	409	459	503	592	436
AVG	**466**	**335**	**268**	**280**	**322**	**294**	**406**	**265**
STDEV	**113**	**89**	**50**	**68**	**92**	**93**	**163**	**80**
SEM	**25**	**20**	**11**	**15**	**21**	**21**	**36**	**18**

APPENDIX for CHAPTER 5: Effect of ageing and direction on saccadic eye movements

AMPLITUDE (Degrees) / GROUP I (20-39 years)

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AS	10.51	8.58	12.44	7.64	18.55	7.63	10.17	6.38
AR	7.48	10.88	5.53	9.2	5.94	8.17	7.93	8.26
AB	10.34	6.43	7.48	11.04	7.89	7.57	9.95	7.38
AN	13.75	8.19	7.65	9.4	10.9	8.62	11.22	10
AM	12.74	9.37	9.03	8.64	8.78	8.2	9.05	5.77
CH	12.78	8.23	9.08	9.4	10.28	7.12	12.66	9.62
DC	11.7	9.43	9.38	6.36	8.97	8.02	11.16	9.33
EP	11.37	7.83	8.4	10.46	13.53	10.51	9.72	11.57
EL	12.65	8.18	9.03	6.32	10.18	10.5	11.03	5.03
EG	8.99	8.8	9.65	6.74	8.82	8.16	9.08	6.8
IM	10.89	11.2	7.55	7.26	11.29	9.21	9.63	8.6
IU	9.83	6.05	8.75	9.52	8.4	9.32	10.49	7.6
KH	8.6	10.83	8.55	9.96	12.9	7.87	10.3	9.12
MB	7.75	13.35	9.13	9.1	10.8	9.59	10.01	7.42
MM	6.19	10.29	8.75	7.12	13.94	11.78	11.83	9.75
PM	5.2	10.18	8.96	8.49	12.72	6.8	8.89	9.56
PK	8	8.8	11.53	7.13	11.16	7.67	10.19	8.18
RS	11.86	8.66	5.64	7.88	7.04	7.58	8.8	6.6
SN	11.21	10.02	7.94	11.49	11	4.97	9.1	9.84
VA	10.53	11.33	9.26	6.06	12.19	10.54	12.11	7.29
AVG	**10.12**	**9.33**	**8.69**	**8.46**	**10.76**	**8.49**	**10.17**	**8.21**
STDEV	**2.33**	**1.74**	**1.59**	**1.62**	**2.83**	**1.57**	**1.22**	**1.66**
SEM	**0.52**	**0.39**	**0.36**	**0.36**	**0.63**	**0.35**	**0.27**	**0.37**

AMPLITUDE (Degrees) / GROUP II (40-59 years)

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AP	12.74	11.52	7.26	8.76	7.58	7.98	10.57	6.82
CV	10.78	8.47	9.59	9.61	9.41	6.21	8.75	4.61
DT	9.55	9.73	5.55	8.08	7.95	12.83	8.18	6.31
JB	10.05	7.98	7.27	8.26	10.38	4.99	6.43	6.29
LS	11.04	11	8.35	5.59	11.83	5.24	11.72	5.13
SL	12.84	7.22	9.45	9.54	10.58	7.42	8.74	6.17
SA	8.53	12.4	9.62	5.09	13.05	4.82	10.07	6.48
DB	10.8	11.09	13.51	6.19	7.46	6.61	12.45	2.58
GC	9.94	9.04	9.44	8.95	14.48	6.31	9.94	3.79
JL	9.49	8.91	8.89	8.16	10.1	7.5	12.71	7.22
LK	11.55	9.11	9.83	6.88	10.27	8.74	10.72	7.99
SHE	11.02	7.39	8.14	8.15	8.52	6.93	11.73	8.91
SH	11.87	9.43	8.64	8.18	10.91	10.33	9.05	10.44
BD	10.9	8.63	9.64	8.79	11.43	10.08	11.29	9.69
DK	11.63	8.26	10.03	8.41	9.55	7.52	10.2	8.27
GB	7.67	8.88	9.21	8.44	9.54	7.82	12.08	7.2
LB	15.1	6.08	8.88	7.01	8.97	7.9	8.78	4.91
MT	13.04	7.69	9.2	8.22	11.15	7.83	17.46	7.02
SF	10.43	9.86	9.9	7.7	11.67	5.46	10.98	4.67
TK	11.73	10.6	8.18	10.62	9.69	11.54	11.52	11.02
AVG	**11.04**	**9.16**	**9.03**	**8.03**	**10.23**	**7.70**	**10.67**	**6.78**
STDEV	**1.68**	**1.59**	**1.53**	**1.34**	**1.78**	**2.15**	**2.27**	**2.19**
SEM	**0.37**	**0.35**	**0.34**	**0.30**	**0.40**	**0.48**	**0.51**	**0.49**

AMPLITUDE (Degrees) / GROUP III (60-89 years)

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
EB	7.78	8.88	9.87	8.82	7.54	6.71	8.64	5.81
HC	10.59	9.28	9.2	6.97	9.86	9.23	9.66	10.72
IG	14.18	12.91	8.73	7.52	13.1	6.47	18.06	7.01
JO	8.03	9.31	7.8	9.43	12.4	9.11	9.57	7.52
MS	12.91	10.27	12.38	7.21	8.27	7.47	12.04	6.12
VG	10.47	9.88	9.04	7	9.21	7.22	10.65	7.16
WS	8.67	10.21	11.15	8.75	9.47	6.07	10.13	9.29
BW	7.66	9.85	10.26	6.61	12.35	6.91	10.17	7.25
ES	8.39	10.59	9.1	6.75	13.48	7.11	8.93	8.7
HR	7.91	9.8	11.7	7.91	14.54	10.42	10.37	8.29
JHE	5.1	11	5.65	9.98	13.09	4.18	8.46	9.84
JR	6.45	9.49	8.77	9.24	10.55	7.3	8.1	9.23
WC	9.19	8.9	8.8	8.57	9.62	8.7	11.7	6.12
DBE	9.5	10.47	6.08	9.82	10.85	10.34	7.44	6.95
HO	10.72	9.86	10.98	8.92	10.25	9.32	12.53	7.2
IB	10.84	8.64	12.15	9.96	9.65	8.56	9.78	7
JHO	14.02	11.72	13.3	8.58	10.93	9.26	15.56	5.68
MBU	8.89	9.64	10.84	6.3	8.34	6.98	9.07	6.33
RT	7.98	10.75	10.58	7.95	11.55	10.3	13.5	9.67
WHS	12.13	7.85	9.82	8.64	10.67	6.56	11.99	3.93
AVG	**9.57**	**9.97**	**9.81**	**8.25**	**10.79**	**7.91**	**10.82**	**7.49**
STDEV	**2.41**	**1.13**	**1.96**	**1.17**	**1.90**	**1.66**	**2.61**	**1.69**
SEM	**0.54**	**0.25**	**0.44**	**0.26**	**0.42**	**0.37**	**0.58**	**0.38**

APPENDIX for CHAPTER 5: Effect of ageing and direction on saccadic eye movements

DURATION (msecs) / GROUP I (20-39 years)

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AS	44	44	73	47	91	52	61	40
AR	37	48	37	51	35	57	35	48
AB	48	38	91	95	51	44	48	43
AN	44	63	87	53	82	45	48	48
AM	41	43	45	48	86	45	45	40
CH	44	52	52	52	53	54	43	50
DC	42	44	59	46	44	39	47	42
EP	38	46	67	50	112	44	62	55
EL	45	49	72	45	116	51	84	46
EG	56	51	100	48	70	49	73	42
IM	42	44	65	47	49	108	71	49
IU	49	54	104	57	61	63	59	51
KH	48	44	47	56	60	43	47	40
MB	74	64	55	60	61	45	53	46
MM	81	50	50	53	116	67	104	51
PM	39	52	51	56	62	45	53	46
PK	50	64	47	44	87	64	81	59
RS	47	51	62	46	79	48	58	54
SN	51	45	41	49	109	32	45	40
VA	34	41	73	55	55	36	66	50
AVG	**48**	**49**	**64**	**53**	**74**	**52**	**59**	**47**
STDEV	**12**	**7**	**19**	**11**	**25**	**16**	**17**	**6**
SEM	**3**	**2**	**4**	**2**	**6**	**4**	**4**	**1**

DURATION (msecs) / GROUP II (40-59 years)

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AP	38	44	79	41	44	38	43	43
CV	37	41	75	50	105	34	45	40
DT	50	47	36	43	46	44	47	45
JB	40	51	56	43	71	51	51	40
LS	35	41	45	49	66	41	40	35
SL	41	45	85	51	102	41	51	40
SA	41	40	69	41	64	33	48	32
DB	49	48	99	68	64	47	62	34
GC	55	52	78	61	54	43	43	32
JL	45	51	53	43	79	45	57	44
LK	50	54	76	50	47	51	47	53
SHE	41	45	48	41	35	44	44	38
SH	40	44	62	48	50	41	59	44
BD	54	55	90	60	65	51	93	57
DK	48	50	64	58	71	47	55	47
GB	37	59	59	40	88	38	37	46
LB	36	35	83	44	76	47	37	40
MT	44	43	40	37	42	46	41	47
SF	37	37	59	44	104	37	85	42
TK	37	34	45	42	33	37	33	39
AVG	**43**	**46**	**65**	**48**	**65**	**43**	**51**	**42**
STDEV	**6**	**7**	**18**	**8**	**22**	**5**	**15**	**6**
SEM	**1**	**2**	**4**	**2**	**5**	**1**	**3**	**1**

DURATION (msecs) / GROUP III (60-89 years)

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
EB	46	50	65	48	55	45	43	47
HC	45	46	69	55	59	45	44	43
IG	47	44	46	51	86	44	53	46
JO	50	54	51	45	54	47	68	51
MS	40	43	86	52	51	42	44	44
VG	55	43	118	62	66	59	98	45
WS	65	58	131	168	114	92	63	115
BW	41	50	47	40	86	42	44	37
ES	40	47	47	42	97	39	52	41
HR	64	55	100	61	125	59	68	60
JHE	68	56	64	72	138	46	79	63
JR	44	53	61	70	68	49	79	87
WC	62	52	161	59	76	59	41	54
DBE	41	46	61	57		43	36	54
HO	50	47	58	65	113	48	47	44
IB	56	56	103	59	62	54	90	56
JHO	81	87	114	53	49	48	67	59
MBU	62	64	142	141	144	140	130	131
RT	47	50		56	53	51	44	50
WHS	61	134	79	66	142	56	85	72
AVG	**53**	**57**	**84**	**66**	**86**	**55**	**64**	**60**
STDEV	**11**	**21**	**35**	**32**	**33**	**23**	**24**	**25**
SEM	**3**	**5**	**8**	**7**	**7**	**5**	**5**	**6**

APPENDIX for Chapter 6

This appendix includes the averaged values (from four individual runs) for each saccadic parameter (latency, peak velocity, amplitude and duration) in all eight directions under investigation for each observer at both viewing distances [far (300 cm) and near (49cm)]. At the bottom of each column there is the average, standard deviation and standard error of the mean of all observers in that specific direction of gaze and viewing distance.

APPENDIX for CHAPTER 6: Effect of viewing distance (far vs near) on saccadic eye movements

LATENCY (msecs) / FAR

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AR	219	226	262	206	231	220	235	205
AB	241	215	273	276	271	257	261	248
MB	188	169	230	246	250	218	213	186
DC	230	227	215	240	203	222	188	218
EG	321	311	280	306	282	309	272	338
FM	272	215	245	258	232	246	237	257
GT	238	211	259	300	284	238	291	260
CH	197	199	246	257	243	232	268	251
IU	209	196	231	240	214	224	229	227
JD	237	217	268	321	234	231	255	225
KH	271	273	255	261	259	260	269	295
LC	226	225	226	249	219	208	205	205
EL	287	235	246	268	235	210	257	231
BM	259	250	270	245	265	286	255	265
PM	219	183	193	279	205	209	203	187
EP	255	236	249	258	244	230	242	246
PK	276	233	254	277	247	238	282	199
RS	236	268	224	236	210	257	235	229
SN	237	219	204	263	241	255	248	245
XV	223	239	262	245	251	271	244	255
AVG	**242**	**227**	**244**	**261**	**241**	**241**	**244**	**238**
STDEV	**32**	**32**	**24**	**27**	**24**	**27**	**27**	**36**
SEM	**7**	**7**	**5**	**6**	**5**	**6**	**6**	**8**

LATENCY (msecs) / NEAR

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AR	211	221	214	216	205	190	236	224
AB	259	211	240	242	221	242	240	223
MB	217	246	262	259	266	321	263	230
DC	223	230	215	263	227	215	192	231
EG	263	309	277	309	265	326	270	271
FM	267	210	222	237	215	273	251	244
GT	232	216	267	250	289	274	343	250
CH	255	276	270	294	233	288	241	262
IU	257	206	213	231	214	203	201	222
JD	209	192	293	280	231	250	283	234
KH	234	237	241	255	231	246	260	268
LC	190	211	192	225	192	231	198	232
EL	213	237	248	275	233	240	257	228
BM	225	233	251	232	228	227	228	218
PM	223	222	194	213	196	217	197	230
EP	224	236	206	250	212	243	218	267
PK	217	225	246	219	210	231	238	203
RS	242	195	281	232	219	271	216	308
SN	294	228	217	249	208	235	221	228
XV	248	264	250	276	250	258	233	277
AVG	**235**	**230**	**240**	**250**	**227**	**249**	**239**	**242**
STDEV	**25**	**28**	**30**	**26**	**24**	**35**	**35**	**26**
SEM	**6**	**6**	**7**	**6**	**5**	**8**	**8**	**6**

PEAK VELOCITY (Deg/sec) / FAR

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AR	324	357	246	336	325	348	356	401
AB	361	335	266	246	146	276	360	412
MB	307	406	222	320	288	397	414	341
DC	442	226	289	293	314	253	439	286
EG	245	246	271	270	261	343	378	353
FM	406	288	365	215	392	286	401	259
GT	261	162	273	359	366	289	300	264
CH	329	425	310	417	431	306	415	419
IU	294	353	247	329	261	352	283	335
JD	312	250	237	165	245	232	378	316
KH	434	214	322	290	286	272	419	238
LC	468	405	249	207	290	265	359	244
EL	489	359	309	234	367	334	421	376
BM	490	251	224	256	371	307	396	333
PM	369	265	255	284	289	267	256	365
EP	357	354	202	286	264	342	196	369
PK	410	310	225	173	155	313	325	329
RS	455	354	190	281	357	384	281	304
SN	324	269	250	180	225	321	227	284
XV	498	332	332	221	348	410	642	420
AVG	**379**	**308**	**264**	**268**	**299**	**315**	**362**	**332**
STDEV	**79**	**71**	**45**	**65**	**74**	**49**	**96**	**58**
SEM	**18**	**16**	**10**	**15**	**17**	**11**	**21**	**13**

PEAK VELOCITY (Deg/sec) / NEAR

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AR	328	340	195	274	198	251	285	215
AB	426	375	359	418	298	287	363	303
MB	499	387	455	384	469	417	447	296
DC	382	284	391	402	317	345	395	373
EG	364	281	251	269	266	284	332	320
FM	381	320	315	321	296	434	609	383
GT	260	387	223	258	208	239	256	298
CH	360	380	286	253	312	336	341	226
IU	272	314	222	369	358	318	212	344
JD	421	263	319	246	338	344	298	263
KH	281	339	271	266	235	379	316	290
LC	351	355	218	388	351	304	349	426
EL	497	268	375	311	319	347	331	291
BM	438	324	301	275	353	396	325	275
PM	398	352	157	381	355	310	227	363
EP	573	350	197	379	460	408	344	458
PK	386	237	256	306	234	342	205	430
RS	346	392	285	341	314	338	246	306
SN	415	244	204	299	203	331	184	311
XV	455	261	296	544	398	384	653	406
AVG	**392**	**323**	**279**	**334**	**314**	**340**	**336**	**329**
STDEV	**79**	**51**	**76**	**74**	**77**	**53**	**121**	**67**
SEM	**18**	**11**	**17**	**17**	**17**	**12**	**27**	**15**

APPENDIX for CHAPTER 6: Effect of viewing distance (far vs near) on saccadic eye movements

AMPLITUDE (Degrees) / FAR

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AR	9.43	9.46	7.81	9.21	11.66	8.68	9.46	8.33
AB	8.95	10.01	9.95	8.05	9.25	7.08	9.94	10.85
MB	7.03	10.27	5.46	8.95	6.33	8.20	8.12	9.59
DC	11.75	8.12	9.16	7.81	8.80	7.40	10.77	7.65
EG	9.20	9.84	10.49	9.60	9.83	10.42	11.58	8.97
FM	11.16	8.91	10.43	6.44	11.44	9.10	10.64	6.21
GT	9.51	7.78	5.87	10.33	11.77	8.70	12.06	7.36
CH	8.48	10.73	8.30	10.37	12.65	7.58	10.22	9.34
IU	8.80	10.32	10.31	10.55	11.23	10.59	10.25	9.76
JD	9.91	8.45	9.07	6.14	9.06	7.38	10.06	7.11
KH	12.05	6.49	8.14	9.27	11.19	8.17	8.40	6.76
LC	11.10	11.45	9.95	7.57	8.59	6.75	9.13	6.57
EL	11.51	9.74	9.80	7.46	9.66	8.35	10.61	9.04
BM	9.67	7.16	8.62	6.76	9.02	6.59	9.64	7.36
PM	10.65	8.14	8.98	8.82	9.48	8.02	6.91	8.24
EP	10.13	9.65	8.20	8.89	9.79	9.05	9.78	9.60
PK	10.91	9.35	10.50	7.33	10.27	10.91	10.76	10.01
RS	10.62	10.39	8.27	7.70	11.03	9.57	10.42	9.46
SN	9.47	9.25	7.41	7.62	10.25	9.03	6.75	10.49
XV	10.84	9.27	8.87	6.39	8.88	10.10	12.85	9.11
AVG	**10.06**	**9.24**	**8.78**	**8.26**	**10.01**	**8.58**	**9.92**	**8.59**
STDEV	**1.25**	**1.24**	**1.43**	**1.37**	**1.45**	**1.28**	**1.53**	**1.37**
SEM	**0.28**	**0.28**	**0.32**	**0.31**	**0.32**	**0.29**	**0.34**	**0.31**

AMPLITUDE (Degrees) / NEAR

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AR	9.50	7.94	7.38	7.60	7.37	7.02	10.08	6.37
AB	10.60	10.65	8.53	9.37	7.68	7.51	9.88	7.63
MB	11.96	10.80	11.38	9.56	9.81	9.68	10.81	7.10
DC	10.29	8.55	9.02	8.98	10.41	9.50	9.88	10.61
EG	10.15	10.39	8.53	10.10	9.63	8.74	9.23	10.99
FM	9.09	9.23	8.78	9.48	7.94	9.51	12.59	9.32
GT	9.74	11.90	6.82	10.35	7.06	8.26	10.70	8.89
CH	9.80	10.68	9.79	8.04	10.46	11.21	12.75	6.29
IU	9.38	10.49	10.50	9.84	10.65	12.16	7.60	10.45
JD	11.58	8.03	9.65	9.05	10.03	10.29	8.50	7.37
KH	7.58	8.18	7.01	9.37	6.95	10.15	8.60	7.75
LC	9.62	9.90	8.78	10.95	9.52	9.26	9.81	11.81
EL	11.38	7.13	9.39	11.02	9.59	10.43	9.11	7.32
BM	10.48	9.11	8.03	6.88	8.48	8.81	9.69	7.34
PM	11.19	10.69	7.06	9.00	9.56	9.35	9.36	11.45
EP	12.91	9.25	5.39	10.00	11.29	11.05	9.85	10.95
PK	11.34	7.30	10.35	9.21	8.74	10.87	8.81	11.12
RS	9.20	9.48	10.32	9.34	10.18	9.03	10.46	10.34
SN	11.56	6.99	6.10	13.38	7.48	9.00	6.63	9.94
XV	10.63	7.08	7.20	10.34	8.92	9.03	12.32	8.44
AVG	**10.40**	**9.19**	**8.50**	**9.59**	**9.09**	**9.54**	**9.83**	**9.07**
STDEV	**1.22**	**1.48**	**1.60**	**1.36**	**1.31**	**1.25**	**1.54**	**1.83**
SEM	**0.27**	**0.33**	**0.36**	**0.30**	**0.29**	**0.28**	**0.34**	**0.41**

DURATION (msecs) / FAR

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AR	52	48	56	48	94	38	49	34
AB	42	49	75	49	112	44	49	44
MB	34	45	37	55	37	62	33	53
DC	54	53	67	43	44	49	44	44
EG	62	66	96	62	97	44	50	55
FM	52	51	52	56	56	60	55	52
GT	60	81	56	62	61	58	77	55
CH	46	44	46	56	60	39	44	39
IU	46	54	86	54	76	45	64	43
JD	60	58	95	65	86	57	53	49
KH	45	55	78	71	83	58	52	50
LC	47	53	73	66	55	46	51	51
EL	46	45	67	54	45	42	44	44
BM	51	55	79	55	56	46	56	48
PM	48	49	84	45	72	44	43	64
EP	49	50	77	44	79	40	87	42
PK	47	50	96	84	135	64	67	54
RS	46	45	77	50	50	42	73	54
SN	45	55	63	70	75	53	54	75
XV	45	49	55	64	52	49	46	46
AVG	**49**	**53**	**71**	**57**	**71**	**49**	**54**	**50**
STDEV	**7**	**8**	**17**	**10**	**25**	**8**	**13**	**9**
SEM	**1**	**2**	**4**	**2**	**6**	**2**	**3**	**2**

DURATION (msecs) / NEAR

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AR	56	55	91	55	91	58	88	62
AB	51	53	49	64	53	51	56	52
MB	40	41	48	45	43	38	42	40
DC	53	56	54	54	55	59	54	60
EG	56	63	86	75	72	56	55	69
FM	50	51	55	59	51	49	50	49
GT	76	58	60	88	62	64	69	56
CH	55	46	86	57	64	55	82	53
IU	62	67	118	55	69	82	75	62
JD	58	57	85	68	55	59	62	56
KH	54	53	76	72	64	64	56	55
LC	53	53	83	68	51	57	55	58
EL	47	45	54	65	72	63	68	57
BM	48	53	67	55	53	48	65	53
PM	54	55	111	58	52	57	102	70
EP	51	51	57	53	49	52	54	47
PK	58	59	93	67	63	66	89	68
RS	51	51	94	54	66	52	85	65
SN	50	52	59	73	62	52	62	66
XV	46	49	53	46	48	45	44	44
AVG	**53**	**53**	**74**	**61**	**59**	**56**	**65**	**57**
STDEV	**7**	**6**	**21**	**11**	**11**	**9**	**16**	**8**
SEM	**2**	**1**	**5**	**2**	**2**	**2**	**4**	**2**

APPENDIX for Chapter 7

This appendix shows the data (averaged values from four individual runs) of each observer that were collected for each saccadic parameter in all the eight directions for three different levels of defocus (0.00 DS, +1.00DS and +3.00DS). The DEF 0 corresponds to the 0.00 level of defocus (required prescription), the DEF 1 corresponds to the +1.00 level of defocus whereas the DEF 3 corresponds to the +3.00 level of defocus. At the bottom of each column there is the average, standard deviation and standard error of the mean of all observers in that specific direction of gaze and level of defocus respectively.

APPENDIX for CHAPTER 7: The effect of defocus on saccadic eye movements

LATENCY (msecs) / DEF 0

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AR	219	226	262	206	231	220	235	205
AB	241	215	273	276	271	257	261	248
MB	188	169	230	246	250	218	213	186
DC	230	227	215	240	203	222	188	218
EG	321	311	280	306	282	309	272	338
FM	272	215	245	258	232	246	237	257
GT	238	211	259	300	284	238	291	260
CH	197	199	246	257	243	232	268	251
IU	209	196	231	240	214	224	229	227
JD	237	217	268	321	234	231	255	225
KH	271	273	255	261	259	260	269	295
LC	226	225	226	249	219	208	205	205
EL	287	235	246	268	235	210	257	231
BM	259	250	270	245	265	286	255	265
PM	219	183	193	279	205	209	203	187
EP	255	236	249	258	244	230	242	246
PK	276	233	254	277	247	238	282	199
RS	236	268	224	236	210	257	235	229
SN	237	219	204	263	241	255	248	245
XV	223	239	262	245	251	271	244	255
AVG	**242**	**227**	**244**	**261**	**241**	**241**	**244**	**238**
STDEV	**32**	**32**	**24**	**27**	**24**	**27**	**27**	**36**
SEM	**7**	**7**	**5**	**6**	**5**	**6**	**6**	**8**

LATENCY (msecs) / DEF 1

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AR	206	205	242	202	201	205	200	202
AB	276	274	278	253	230	253	266	213
MB	253	217	228	271	232	248	218	249
DC	220	236	236	246	238	261	258	249
EG	263	315	252	268	282	266	254	286
FM	214	192	209	253	228	268	246	262
GT	228	249	304	253	241	263	292	261
CH	234	247	253	251	284	271	253	276
IU	261	220	223	234	216	252	196	233
JD	223	201	246	306	236	226	241	212
KH	244	252	270	300	320	277	299	279
LC	217	241	201	258	221	216	202	231
EL	235	223	250	257	233	275	243	223
BM	241	242	262	262	252	263	244	212
PM	219	211	229	194	223	226	213	207
EP	243	239	256	260	232	235	227	266
PK	239	238	239	234	226	210	240	225
RS	261	242	259	256	232	267	232	223
SN	240	276	217	248	238	269	223	230
XV	208	268	240	245	238	273	245	283
AVG	**236**	**239**	**244**	**252**	**240**	**251**	**239**	**241**
STDEV	**20**	**29**	**24**	**26**	**27**	**23**	**28**	**28**
SEM	**4**	**7**	**5**	**6**	**6**	**5**	**6**	**6**

LATENCY (msecs) / DEF 3

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AR	180	205	295	205	208	232	260	206
AB	262	245	332	238	248	245	226	233
MB	224	238	244	258	207	222	232	239
DC	256	211	224	251	243	225	247	232
EG	300	295	260	301	298	277	281	282
FM	292	229	226	268	195	253	257	234
GT	238	257	263	249	286	233	263	230
CH	229	220	255	276	246	248	250	264
IU	235	247	210	227	220	206	234	242
JD	269	231	280	341	231	307	297	231
KH	301	271	250	266	274	270	291	325
LC	209	256	223	244	236	216	227	238
EL	239	232	238	284	249	263	245	238
BM	243	262	276	276	244	260	243	237
PM	247	196	216	192	220	244	221	221
EP	286	235	305	303	276	246	239	262
PK	213	248	291	247	243	247	246	241
RS	285	255	341	259	225	243	255	261
SN	240	215	225	247	206	219	202	241
XV	234	259	244	254	273	264	266	298
AVG	**249**	**240**	**260**	**259**	**241**	**246**	**249**	**248**
STDEV	**32**	**24**	**38**	**33**	**29**	**24**	**23**	**28**
SEM	**7**	**5**	**8**	**7**	**6**	**5**	**5**	**6**

APPENDIX for CHAPTER 7: The effect of defocus on saccadic eye movements

PEAK VELOCITY (Deg/sec) / DEF 0

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AR	324	357	246	336	325	348	356	401
AB	361	335	266	246	146	276	360	412
MB	307	406	222	320	288	397	414	341
DC	442	226	289	293	314	253	439	286
EG	245	246	271	270	261	343	378	353
FM	406	288	365	215	392	286	401	259
GT	261	162	273	359	366	289	300	264
CH	329	425	310	417	431	306	415	419
IU	294	353	247	329	261	352	283	335
JD	312	250	237	165	245	232	378	316
KH	434	214	322	290	286	272	419	238
LC	468	405	249	207	290	265	359	244
EL	489	359	309	234	367	334	421	376
BM	490	251	224	256	371	307	396	333
PM	369	265	255	284	289	267	256	365
EP	357	354	202	286	264	342	196	369
PK	410	310	225	173	155	313	325	329
RS	455	354	190	281	357	384	281	304
SN	324	269	250	180	225	321	227	284
XV	498	332	332	221	348	410	642	420
AVG	**379**	**308**	**264**	**268**	**299**	**315**	**362**	**332**
STDEV	**79**	**71**	**45**	**65**	**74**	**49**	**96**	**58**
SEM	**18**	**16**	**10**	**15**	**17**	**11**	**21**	**13**

PEAK VELOCITY (Deg/sec) / DEF 1

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AR	372	367	184	239	253	253	692	354
AB	462	433	265	204	318	302	544	365
MB	518	460	277	295	352	377	600	276
DC	423	238	263	186	315	219	442	288
EG	378	211	295	291	316	294	305	329
FM	342	260	246	304	428	315	433	383
GT	225	221	152	225	282	198	241	112
CH	494	334	254	207	373	346	481	525
IU	282	377	330	300	261	226	299	330
JD	298	297	245	123	333	214	376	238
KH	335	278	333	214	285	229	246	209
LC	343	341	270	352	245	314	294	318
EL	431	387	363	189	373	197	411	377
BM	380	353	250	217	296	352	548	329
PM	276	302	198	287	317	194	361	302
EP	301	358	206	393	526	325	381	404
PK	316	251	231	326	228	235	204	207
RS	372	333	198	249	266	265	350	358
SN	335	224	267	166	227	250	267	283
XV	492	286	302	295	686	388	697	437
AVG	**369**	**316**	**256**	**253**	**334**	**275**	**409**	**321**
STDEV	**80**	**71**	**53**	**68**	**109**	**62**	**146**	**90**
SEM	**18**	**16**	**12**	**15**	**24**	**14**	**33**	**20**

PEAK VELOCITY (Deg/sec) / DEF 3

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AR	360	370	204	249	212	244	360	275
AB	307	349	172	224	210	280	592	177
MB	414	381	366	245	256	375	313	310
DC	339	233	273	270	313	233	431	337
EG	347	266	260	270	260	298	269	313
FM	335	269	290	218	367	383	429	354
GT	220	215	376	227	229	236	256	239
CH	258	331	319	242	383	316	313	284
IU	209	254	441	181	353	217	203	157
JD	288	267	325	130	281	195	372	238
KH	312	264	266	231	218	199	324	206
LC	371	290	263	225	322	181	322	379
EL	564	444	346	223	266	196	404	444
BM	370	356	188	245	303	230	464	329
PM	265	316	176	305	276	224	275	228
EP	288	373	171	294	383	282	348	405
PK	384	241	215	333	226	205	256	243
RS	278	354	172	150	189	296	216	250
SN	286	222	225	170	190	259	287	282
XV	522	295	260	300	357	354	581	427
AVG	**336**	**305**	**265**	**237**	**280**	**260**	**351**	**294**
STDEV	**89**	**63**	**78**	**52**	**65**	**61**	**107**	**80**
SEM	**20**	**14**	**17**	**12**	**14**	**14**	**24**	**18**

APPENDIX for CHAPTER 7: The effect of defocus on saccadic eye movements

AMPLITUDE (Degrees) / DEF 0

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AR	9.43	9.46	7.81	9.21	11.66	8.68	9.46	8.33
AB	8.95	10.01	9.95	8.05	9.25	7.08	9.94	10.85
MB	7.03	10.27	5.46	8.95	6.33	8.20	8.12	9.59
DC	11.75	8.12	9.16	7.81	8.80	7.40	10.77	7.65
EG	9.20	9.84	10.49	9.60	9.83	10.42	11.58	8.97
FM	11.16	8.91	10.43	6.44	11.44	9.10	10.64	6.21
GT	9.51	7.78	5.87	10.33	11.77	8.70	12.06	7.36
CH	8.48	10.73	8.30	10.37	12.65	7.58	10.22	9.34
IU	8.80	10.32	10.31	10.55	11.23	10.59	10.25	9.76
JD	9.91	8.45	9.07	6.14	9.06	7.38	10.06	7.11
KH	12.05	6.49	8.14	9.27	11.19	8.17	8.40	6.76
LC	11.10	11.45	9.95	7.57	8.59	6.75	9.13	6.57
EL	11.51	9.74	9.80	7.46	9.66	8.35	10.61	9.04
BM	9.67	7.16	8.62	6.76	9.02	6.59	9.64	7.36
PM	10.65	8.14	8.98	8.82	9.48	8.02	6.91	8.24
EP	10.13	9.65	8.20	8.89	9.79	9.05	9.78	9.60
PK	10.91	9.35	10.50	7.33	10.27	10.91	10.76	10.01
RS	10.62	10.39	8.27	7.70	11.03	9.57	10.42	9.46
SN	9.47	9.25	7.41	7.62	10.25	9.03	6.75	10.49
XV	10.84	9.27	8.87	6.39	8.88	10.10	12.85	9.11
AVG	**10.06**	**9.24**	**8.78**	**8.26**	**10.01**	**8.58**	**9.92**	**8.59**
STDEV	**1.25**	**1.24**	**1.43**	**1.37**	**1.45**	**1.28**	**1.53**	**1.37**
SEM	**0.28**	**0.28**	**0.32**	**0.31**	**0.32**	**0.29**	**0.34**	**0.31**

AMPLITUDE (Degrees) / DEF 3

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AR	8.38	10.23	8.07	7.71	8.87	7.03	11.97	7.00
AB	8.67	10.65	5.35	8.95	6.41	7.38	13.77	4.97
MB	11.24	11.66	8.92	7.89	9.82	10.59	8.47	8.04
DC	10.41	8.25	9.73	9.64	10.62	6.97	11.34	9.96
EG	11.42	10.21	9.29	9.27	10.52	8.28	8.47	9.89
FM	10.48	8.43	10.28	6.59	11.21	8.97	12.88	7.79
GT	8.63	8.60	9.55	8.01	7.62	8.13	11.17	7.39
CH	8.82	9.82	9.52	7.99	11.70	9.51	10.18	8.90
IU	7.88	8.31	12.47	6.08	11.72	6.07	9.55	6.16
JD	10.08	9.49	12.90	5.43	11.63	6.52	10.59	7.01
KH	9.62	7.97	8.7	8.49	8.35	6.35	10.12	6.35
LC	10.41	8.87	9.31	7.97	10.01	4.92	9.84	11.13
EL	15.03	12.30	9.86	7.87	10.27	6.57	12.03	9.57
BM	8.14	8.59	7.65	6.25	8.76	5.39	12.13	6.59
PM	8.45	10.43	8.70	9.85	8.71	8.52	9.32	9.40
EP	9.03	10.19	8.07	7.77	11.24	8.93	11.90	11.19
PK	11.15	8.44	10.07	9.47	10.28	6.43	11.60	7.94
RS	8.52	11.27	10.82	5.72	7.28	9.53	11.06	7.53
SN	9.33	8.61	8.44	7.79	8.11	8.26	10.41	8.31
XV	11.72	8.74	7.39	8.25	9.06	7.30	11.94	8.50
AVG	**9.87**	**9.55**	**9.25**	**7.85**	**9.61**	**7.58**	**10.94**	**8.18**
STDEV	**1.70**	**1.27**	**1.69**	**1.28**	**1.57**	**1.50**	**1.41**	**1.66**
SEM	**0.38**	**0.28**	**0.38**	**0.29**	**0.35**	**0.33**	**0.31**	**0.37**

AMPLITUDE (Degrees) / DEF 1

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AR	8.77	9.39	8.10	6.95	8.66	7.01	15.48	8.91
AB	10.10	13.45	7.39	6.16	7.37	6.34	11.72	8.05
MB	11.36	12.52	7.60	8.62	8.77	9.71	12.73	4.58
DC	11.79	7.93	9.90	6.95	10.22	7.14	11.57	8.14
EG	11.60	8.84	9.43	9.32	11.29	8.16	9.84	9.10
FM	9.21	8.50	7.32	8.85	12.14	8.20	11.90	7.04
GT	8.86	8.80	5.00	9.46	9.57	8.75	11.43	6.12
CH	11.36	10.54	8.62	7.30	12.63	8.94	12.14	13.05
IU	7.46	10.47	10.13	9.89	9.04	7.30	11.09	10.10
JD	9.90	9.76	10.29	5.78	12.30	6.56	11.08	6.89
KH	9.99	8.68	9.08	6.92	10.92	7.71	8.07	5.24
LC	9.66	10.38	11.13	9.58	7.98	7.10	10.09	8.09
EL	10.96	9.04	10.20	6.77	12.19	5.66	10.71	9.32
BM	8.02	9.15	9.15	6.68	9.00	7.86	12.19	7.47
PM	8.64	8.88	7.76	9.19	9.64	8.21	11.57	7.78
EP	7.85	9.84	8.77	10.46	14.30	10.32	12.30	10.33
PK	10.43	9.20	10.57	10.08	10.08	5.90	8.63	6.70
RS	9.98	11.21	10.00	8.44	9.69	8.94	10.96	10.30
SN	9.54	8.74	9.62	8.36	9.15	7.47	10.19	7.73
XV	11.02	8.48	8.56	8.42	13.04	10.13	13.44	9.02
AVG	**9.82**	**9.69**	**8.93**	**8.21**	**10.40**	**7.87**	**11.36**	**8.20**
STDEV	**1.29**	**1.40**	**1.45**	**1.41**	**1.86**	**1.32**	**1.63**	**1.94**
SEM	**0.29**	**0.31**	**0.32**	**0.32**	**0.42**	**0.29**	**0.36**	**0.43**

APPENDIX for CHAPTER 7: The effect of defocus on saccadic eye movements

DURATION (msecs) / DEF 0

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AR	52	48	56	48	94	38	49	34
AB	42	49	75	49	112	44	49	44
MB	34	45	37	55	37	62	33	53
DC	54	53	67	43	44	49	44	44
EG	62	66	96	62	97	44	50	55
FM	52	51	52	56	56	60	55	52
GT	60	81	56	62	61	58	77	55
CH	46	44	46	56	60	39	44	39
IU	46	54	86	54	76	45	64	43
JD	60	58	95	65	86	57	53	49
KH	45	55	78	71	83	58	52	50
LC	47	53	73	66	55	46	51	51
EL	46	45	67	54	45	42	44	44
BM	51	55	79	55	56	46	56	48
PM	48	49	84	45	72	44	43	64
EP	49	50	77	44	79	40	87	42
PK	47	50	96	84	135	64	67	54
RS	46	45	77	50	50	42	73	54
SN	45	55	63	70	75	53	54	75
XV	45	49	55	64	52	49	46	46
AVG	**49**	**53**	**71**	**57**	**71**	**49**	**54**	**50**
STDEV	**7**	**8**	**17**	**10**	**25**	**8**	**13**	**9**
SEM	**1**	**2**	**4**	**2**	**6**	**2**	**3**	**2**

DURATION (msecs) / DEF 1

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AR	48	50	109	54	78	55	61	48
AB	51	55	65	67	56	53	48	49
MB	43	44	48	51	43	42	37	38
DC	54	61	86	66	67	59	60	57
EG	63	70	83	66	85	53	79	57
FM	50	54	56	56	57	53	54	42
GT	66	70	94	91	62	90	84	103
CH	47	49	56	55	56	48	48	36
IU	61	54	64	70	66	62	67	61
JD	59	62	100	81	88	56	58	53
KH	56	58	63	67	78	63	75	52
LC	54	56	70	63	58	43	58	52
EL	47	46	71	71	80	61	53	57
BM	44	54	85	58	75	45	50	47
PM	56	59	105	71	62	72	76	50
EP	53	54	87	58	52	60	60	52
PK	54	60	87	61	67	51	96	67
RS	55	62	102	61	84	70	60	61
SN	55	65	66	85	74	60	67	52
XV	47	53	57	56	48	53	47	44
AVG	**53**	**57**	**77**	**65**	**67**	**57**	**62**	**54**
STDEV	**6**	**7**	**19**	**11**	**13**	**11**	**14**	**14**
SEM	**1**	**2**	**4**	**2**	**3**	**2**	**3**	**3**

DURATION (msecs) / DEF 3

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AR	56	55	91	59	84	59	74	45
AB	55	54	70	81	66	60	50	55
MB	58	55	58	74	118	54	53	54
DC	62	64	78	63	62	56	65	54
EG	63	68	89	70	93	56	65	61
FM	55	55	68	53	56	48	62	48
GT	68	73	62	97	66	62	80	58
CH	61	57	68	68	61	58	61	57
IU	68	67	67	63	63	59	101	70
JD	64	61	102	73	87	57	55	59
KH	55	56	69	87	91	62	80	58
LC	53	56	69	77	58	49	56	56
EL	48	55	68	68	95	65	61	43
BM	48	58	89	49	75	52	56	50
PM	57	59	113	72	65	70	83	69
EP	58	53	71	54	55	56	61	52
PK	55	63	91	57	74	57	95	68
RS	62	62	129	79	98	66	106	61
SN	62	67	76	75	76	57	68	59
XV	46	55	60	60	51	43	43	43
AVG	**57**	**60**	**79**	**69**	**74**	**57**	**69**	**56**
STDEV	**6**	**6**	**19**	**12**	**18**	**6**	**17**	**8**
SEM	**1**	**1**	**4**	**3**	**4**	**1**	**4**	**2**

APPENDIX for Chapter 8

This appendix represents the data (averaged values from four individual runs) that were collected for each observer and saccadic parameter in all the eight directions without (normal) and with a double visor cataract simulation (cataractous vision). At the bottom of each column there is the average, standard deviation and standard error of the mean of all observers in that specific direction of gaze and viewing conditions (normal versus cataractous vision).

APPENDIX for CHAPTER 8: Effect of cataract simulation on saccadic eye movements

LATENCY (msecs) / NORMAL

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AR	219	226	262	206	231	220	235	205
AB	241	215	273	276	271	257	261	248
MB	188	169	230	246	250	218	213	186
DC	230	227	215	240	203	222	188	218
EG	321	311	280	306	282	309	272	338
FM	272	215	245	258	232	246	237	257
GT	238	211	259	300	284	238	291	260
CH	197	199	246	257	243	232	268	251
IU	209	196	231	240	214	224	229	227
JD	237	217	268	321	234	231	255	225
KH	271	273	255	261	259	260	269	295
LC	226	225	226	249	219	208	205	205
EL	287	235	246	268	235	210	257	231
BM	259	250	270	245	265	286	255	265
PM	219	183	193	279	205	209	203	187
EP	255	236	249	258	244	230	242	246
PK	276	233	254	277	247	238	282	199
RS	236	268	224	236	210	257	235	229
SN	237	219	204	263	241	255	248	245
XV	223	239	262	245	251	271	244	255
AVG	**242**	**227**	**244**	**261**	**241**	**241**	**244**	**238**
STDEV	**32**	**32**	**24**	**27**	**24**	**27**	**27**	**36**
SEM	**7**	**7**	**5**	**6**	**5**	**6**	**6**	**8**

LATENCY (msecs) / CAT_SIM

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AR	225	227	266	231	233	243	399	247
AB	247	266	293	269	263	275	265	240
MB	276	238	298	265	245	273	247	244
DC	245	250	266	271	249	277	258	239
EG	328	344	289	354	343	314	285	320
FM	257	261	249	258	251	243	252	255
GT	252	253	314	303	266	251	275	257
CH	253	271	257	284	333	259	253	240
IU	240	220	264	259	250	297	225	245
JD	258	239	297	321	263	262	256	260
KH	275	272	283	270	281	298	297	276
LC	218	225	220	245	249	236	234	221
EL	262	231	249	289	288	253	254	241
BM	240	260	264	249	255	266	269	262
PM	213	236	227	247	221	238	230	224
EP	235	276	228	262	243	242	249	251
PK	236	257	266	233	237	257	216	342
RS	277	227	282	252	244	280	272	268
SN	240	229	228	249	214	251	231	226
XV	234	272	261	295	289	253	271	298
AVG	**250**	**252**	**265**	**270**	**261**	**263**	**262**	**258**
STDEV	**25**	**28**	**26**	**30**	**33**	**21**	**38**	**31**
SEM	**6**	**6**	**6**	**7**	**7**	**5**	**9**	**7**

PEAK VELOCITY (Deg/sec) / NORMAL

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AR	324	357	246	336	325	348	356	401
AB	361	335	266	246	146	276	360	412
MB	307	406	222	320	288	397	414	341
DC	442	226	289	293	314	253	439	286
EG	245	246	271	270	261	343	378	353
FM	406	288	365	215	392	286	401	259
GT	261	162	273	359	366	289	300	264
CH	329	425	310	417	431	306	415	419
IU	294	353	247	329	261	352	283	335
JD	312	250	237	165	245	232	378	316
KH	434	214	322	290	286	272	419	238
LC	468	405	249	207	290	265	359	244
EL	489	359	309	234	367	334	421	376
BM	490	251	224	256	371	307	396	333
PM	369	265	255	284	289	267	256	365
EP	357	354	202	286	264	342	196	369
PK	410	310	225	173	155	313	325	329
RS	455	354	190	281	357	384	281	304
SN	324	269	250	180	225	321	227	284
XV	498	332	332	221	348	410	642	420
AVG	**379**	**308**	**264**	**268**	**299**	**315**	**362**	**332**
STDEV	**79**	**71**	**45**	**65**	**74**	**49**	**96**	**58**
SEM	**18**	**16**	**10**	**15**	**17**	**11**	**21**	**13**

PEAK VELOCITY (Deg/sec) / CAT_SIM

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AR	428	380	183	284	280	241	461	279
AB	495	307	169	275	202	353	479	406
MB	254	416	361	330	321	346	405	396
DC	389	329	299	264	321	271	403	327
EG	339	233	297	226	289	412	391	267
FM	390	332	291	283	273	361	395	368
GT	315	307	339	267	362	182	229	259
CH	325	369	318	293	402	323	343	354
IU	328	244	241	146	263	337	448	246
JD	327	550	261	213	305	330	354	278
KH	347	400	255	211	396	274	356	250
LC	389	421	329	258	253	248	406	307
EL	389	405	424	259	433	215	415	261
BM	330	327	260	234	413	383	479	252
PM	345	337	229	307	371	257	312	329
EP	391	371	196	264	191	443	352	272
PK	322	200	270	240	209	236	321	244
RS	251	230	191	385	199	306	200	234
SN	352	246	273	234	224	234	308	295
XV	393	314	167	255	330	393	570	492
AVG	**355**	**336**	**268**	**261**	**302**	**307**	**381**	**306**
STDEV	**56**	**83**	**68**	**49**	**76**	**72**	**87**	**68**
SEM	**13**	**19**	**15**	**11**	**17**	**16**	**19**	**15**

APPENDIX for CHAPTER 8: Effect of cataract simulation on saccadic eye movements

AMPLITUDE (Degrees) / NORMAL

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AR	9.43	9.46	7.81	9.21	11.66	8.68	9.46	8.33
AB	8.95	10.01	9.95	8.05	9.25	7.08	9.94	10.85
MB	7.03	10.27	5.46	8.95	6.33	8.20	8.12	9.59
DC	11.75	8.12	9.16	7.81	8.80	7.40	10.77	7.65
EG	9.20	9.84	10.49	9.60	9.83	10.42	11.58	8.97
FM	11.16	8.91	10.43	6.44	11.44	9.10	10.64	6.21
GT	9.51	7.78	5.87	10.33	11.77	8.70	12.06	7.36
CH	8.48	10.73	8.30	10.37	12.65	7.58	10.22	9.34
IU	8.80	10.32	10.31	10.55	11.23	10.59	10.25	9.76
JD	9.91	8.45	9.07	6.14	9.06	7.38	10.06	7.11
KH	12.05	6.49	8.14	9.27	11.19	8.17	8.40	6.76
LC	11.10	11.45	9.95	7.57	8.59	6.75	9.13	6.57
EL	11.51	9.74	9.80	7.46	9.66	8.35	10.61	9.04
BM	9.67	7.16	8.62	6.76	9.02	6.59	9.64	7.36
PM	10.65	8.14	8.98	8.82	9.48	8.02	6.91	8.24
EP	10.13	9.65	8.20	8.89	9.79	9.05	9.78	9.60
PK	10.91	9.35	10.50	7.33	10.27	10.91	10.76	10.01
RS	10.62	10.39	8.27	7.70	11.03	9.57	10.42	9.46
SN	9.47	9.25	7.41	7.62	10.25	9.03	6.75	10.49
XV	10.84	9.27	8.87	6.39	8.88	10.10	12.85	9.11
AVG	**10.06**	**9.24**	**8.78**	**8.26**	**10.01**	**8.58**	**9.92**	**8.59**
STDEV	**1.25**	**1.24**	**1.43**	**1.37**	**1.45**	**1.28**	**1.53**	**1.37**
SEM	**0.28**	**0.28**	**0.32**	**0.31**	**0.32**	**0.29**	**0.34**	**0.31**

AMPLITUDE (Degrees) / CAT_SIM

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AR	10.90	10.08	7.55	7.52	8.40	6.17	11.60	7.06
AB	11.77	9.51	5.43	8.07	10.25	9.26	11.35	10.03
MB	7.61	10.34	8.26	8.98	8.96	9.46	9.30	8.55
DC	10.44	10.08	9.57	9.35	9.40	7.60	10.74	9.27
EG	10.39	8.83	9.97	8.84	10.45	10.70	10.37	9.01
FM	11.00	9.64	8.30	8.16	9.05	9.12	10.95	8.54
GT	9.72	9.88	13.04	8.93	10.47	7.60	8.88	8.66
CH	9.25	10.42	8.68	8.29	12.82	7.69	10.95	9.16
IU	10.24	8.13	10.05	6.70	11.05	11.64	12.31	7.50
JD	10.28	11.07	9.97	8.22	10.01	10.03	10.67	7.66
KH	10.04	11.29	9.07	7.12	12.09	8.55	9.35	8.51
LC	11.15	11.28	11.48	9.02	8.86	7.78	11.66	8.34
EL	9.12	10.53	11.83	6.89	11.11	5.54	10.89	6.09
BM	8.13	8.66	8.82	6.27	11.26	9.44	11.44	5.83
PM	8.97	9.93	9.77	8.88	10.16	7.01	7.97	10.67
EP	11.07	10.87	7.74	7.93	12.19	10.09	8.94	7.07
PK	9.71	7.23	10.64	8.04	9.62	7.49	13.13	8.35
RS	7.62	8.13	6.30	9.71	8.72	9.02	10.07	7.02
SN	10.97	8.84	7.90	10.05	9.42	7.56	11.12	9.14
XV	9.56	8.68	9.69	7.17	9.06	9.98	12.34	9.18
AVG	**9.90**	**9.67**	**9.20**	**8.21**	**10.17**	**8.59**	**10.70**	**8.28**
STDEV	**1.17**	**1.15**	**1.82**	**1.03**	**1.26**	**1.55**	**1.31**	**1.24**
SEM	**0.26**	**0.26**	**0.41**	**0.23**	**0.28**	**0.35**	**0.29**	**0.28**

DURATION (msecs) / NORMAL

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AR	52	48	56	48	94	38	49	34
AB	42	49	75	49	112	44	49	44
MB	34	45	37	55	37	62	33	53
DC	54	53	67	43	44	49	44	44
EG	62	66	96	62	97	44	50	55
FM	52	51	52	56	56	60	55	52
GT	60	81	56	62	61	58	77	55
CH	46	44	46	56	60	39	44	39
IU	46	54	86	54	76	45	64	43
JD	60	58	95	65	86	57	53	49
KH	45	55	78	71	83	58	52	50
LC	47	53	73	66	55	46	51	51
EL	46	45	67	54	45	42	44	44
BM	51	55	79	55	56	46	56	48
PM	48	49	84	45	72	44	43	64
EP	49	50	77	44	79	40	87	42
PK	47	50	96	84	135	64	67	54
RS	46	45	77	50	50	42	73	54
SN	45	55	63	70	75	53	54	75
XV	45	49	55	64	52	49	46	46
AVG	**49**	**53**	**71**	**57**	**71**	**49**	**54**	**50**
STDEV	**7**	**8**	**17**	**10**	**25**	**8**	**13**	**9**
SEM	**1**	**2**	**4**	**2**	**6**	**2**	**3**	**2**

DURATION (msecs) / CAT_SIM

Observers	TEM	NAS	UP	DOWN	UN	DT	UT	DN
AR	56	54	119	55	75	53	67	46
AB	50	56	58	60	121	50	53	50
MB	52	42	54	55	55	52	50	47
DC	58	57	66	64	60	55	55	54
EG	56	66	71	70	64	48	50	62
FM	52	52	58	62	55	50	56	45
GT	55	58	67	70	69	79	67	65
CH	46	47	51	47	55	41	54	44
IU	62	60	84	90	82	67	64	69
JD	59	52	80	71	68	55	61	52
KH	59	57	87	72	59	60	47	67
LC	50	49	65	69	61	57	53	51
EL	38	41	79	59	53	49	56	49
BM	53	51	72	54	61	53	52	49
PM	51	58	115	77	55	67	53	60
EP	52	53	91	53	112	45	53	48
PK	56	61	67	60	73	59	69	64
RS	57	70	74	53	92	61	104	60
SN	62	61	59	69	67	59	70	57
XV	43	50	122	55	50	50	43	40
AVG	**53**	**55**	**77**	**63**	**69**	**55**	**59**	**54**
STDEV	**6**	**7**	**21**	**10**	**19**	**9**	**13**	**9**
SEM	**1**	**2**	**5**	**2**	**4**	**2**	**3**	**2**

APPENDIX for Chapter 9

This appendix represents the data (averaged values from four individual runs) that were collected for each amblyopic observer and saccadic parameter in all the eight directions under investigation. Monocular measurements were made with the amblyopic (AE) and fellow eye (FE) in separate occasions. At the third and fifth column there is standard deviation within the measurements of the FE and AE of each observer.

APPENDIX for CHAPTER 9: Effect of amblyopia on the metrics of saccadic eye

LATENCY (msecs)

TEM

Observers	FE	Stdev	AE	Stdev
1	245	38	365	43
2	244	21	246	18
3	270	21	296	59
4	251	47	275	57
5	248	19	363	73
6	241	67	320	114
7	254	34	321	37
8	257	20	271	22
9	242	18	1330	337

NAS

Observers	FE	Stdev	AE	Stdev
1	284	63	233	27
2	230	19	262	19
3	315	58	266	64
4	241	26	312	62
5	250	29	314	8
6	227	66	331	68
7	238	18	383	60
8	226	18	261	14
9	240	15	366	22

UP

Observers	FE	Stdev	AE	Stdev
1	237	22	291	28
2	226	12	259	21
3	251	19	234	15
4	232	21	278	31
5	279	31	332	25
6	240	9	285	56
7	237	21	291	26
8	282	9	290	45
9	247	24	449	93

DOWN

Observers	FE	Stdev	AE	Stdev
1	252	19	327	83
2	254	27	253	10
3	243	22	301	34
4	247	21	261	47
5	240	12	335	40
6	231	16	308	42
7	250	33	319	29
8	284	3	316	14
9	249	18	462	74

UN

Observers	FE	Stdev	AE	Stdev
1	245	26	246	14
2	221	32	245	7
3	235	16	249	16
4	223	12	271	32
5	307	8	323	39
6	221	32	278	50
7	232	23	347	26
8	279	33	328	26
9	254	20	375	29

DT

Observers	FE	Stdev	AE	Stdev
1	211	26	296	31
2	239	19	230	8
3	250	9	260	43
4	229	35	257	26
5	240	27	317	50
6	262	32	340	64
7	269	30	345	58
8	260	32	316	10
9	241	15	636	118

UT

Observers	FE	Stdev	AE	Stdev
1	271	68	308	74
2	223	19	252	23
3	234	23	257	9
4	240	26	296	54
5	318	30	338	63
6	229	16	327	42
7	263	16	290	16
8	290	16	348	44
9	283	26	500	142

DN

Observers	FE	Stdev	AE	Stdev
1	281	58	273	32
2	208	8	267	81
3	238	18	274	23
4	236	36	248	37
5	283	29	352	54
6	258	36	247	18
7	255	18	302	10
8	264	48	424	27
9	251	32	392	48

APPENDIX for CHAPTER 9: Effect of amblyopia on the metrics of saccadic eye

PEAK VELOCITY (Deg/sec)

TEM

Observers	FE	Stdev	AE	Stdev
1	240	16	286	37
2	353	24	303	44
3	229	8	179	8
4	259	10	186	50
5	385	72	444	85
6	417	36	330	67
7	278	31	310	46
8	263	18	385	38
9	542	22	345	69

NAS

Observers	FE	Stdev	AE	Stdev
1	292	14	249	18
2	292	41	356	68
3	202	0	239	69
4	279	8	277	24
5	397	26	339	39
6	315	37	248	29
7	205	34	293	46
8	338	51	317	27
9	342	4	353	25

UP

Observers	FE	Stdev	AE	Stdev
1	222	19	207	14
2	307	14	219	42
3	183	11	171	19
4	189	11	188	35
5	353	41	284	50
6	148	7	217	26
7	260	35	225	10
8	160	23	196	24
9	375	20	276	12

DOWN

Observers	FE	Stdev	AE	Stdev
1	187	48	163	57
2	411	27	407	27
3	202	53	188	34
4	215	35	208	36
5	306	68	254	42
6	266	36	277	33
7	207	31	240	17
8	283	32	310	34
9	365	42	294	43

UN

Observers	FE	Stdev	AE	Stdev
1	209	15	336	41
2	226	11	304	18
3	204	57	176	32
4	156	13	126	31
5	270	76	432	42
6	302	67	268	33
7	322	82	237	44
8	183	35	175	23
9	273	16	197	6

DT

Observers	FE	Stdev	AE	Stdev
1	265	24	164	14
2	322	37	369	68
3	186	62	179	12
4	274	36	244	32
5	306	89	353	34
6	226	23	206	19
7	223	50	200	10
8	226	15	209	65
9	455	37	222	17

UT

Observers	FE	Stdev	AE	Stdev
1	299	25	346	15
2	349	31	352	23
3	394	30	238	40
4	372	67	178	52
5	424	58	565	61
6	304	64	479	62
7	268	29	369	54
8	249	13	224	54
9	374	50	296	22

DN

Observers	FE	Stdev	AE	Stdev
1	164	26	137	5
2	419	9	297	62
3	223	33	200	49
4	277	16	177	19
5	355	37	342	53
6	225	20	280	26
7	195	34	180	26
8	292	30	323	54
9	383	17	310	16

APPENDIX for CHAPTER 9: Effect of amblyopia on the metrics of saccadic eye

AMPLITUDE (Degrees)

TEM

Observers	FE	Stdev	AE	Stdev
1	8.59	0.43	8.87	1.27
2	9.15	0.77	8.18	0.63
3	7.88	0.41	6.53	0.40
4	8.48	0.23	6.63	0.72
5	10.30	1.07	10.79	1.07
6	12.35	0.67	8.73	0.44
7	9.64	0.16	9.64	0.56
8	7.87	0.28	9.50	1.06
9	11.23	0.53	11.69	0.70

NAS

Observers	FE	Stdev	AE	Stdev
1	11.10	0.23	8.89	0.69
2	8.66	1.55	9.25	0.95
3	7.18	0.05	7.82	1.78
4	8.76	0.19	8.30	0.29
5	9.62	0.45	9.67	0.56
6	9.53	1.11	7.43	0.07
7	8.31	0.44	10.10	0.46
8	9.76	0.86	9.29	0.77
9	9.80	0.41	9.87	0.49

UP

Observers	FE	Stdev	AE	Stdev
1	9.71	0.48	9.47	1.26
2	8.33	0.61	11.16	1.23
3	7.38	0.42	6.31	0.40
4	7.80	0.62	8.71	0.42
5	13.61	1.07	9.08	0.34
6	7.72	0.94	8.51	0.65
7	9.25	0.19	8.37	0.55
8	10.07	0.24	10.54	1.55
9	10.03	0.39	9.43	0.33

DOWN

Observers	FE	Stdev	AE	Stdev
1	7.84	0.69	5.75	0.55
2	10.00	0.60	8.67	0.19
3	7.23	0.49	6.40	0.70
4	9.69	1.20	8.64	0.88
5	10.02	0.56	7.94	0.83
6	8.26	1.15	9.35	0.57
7	6.39	1.02	7.10	0.64
8	8.98	0.41	9.68	1.15
9	9.59	0.27	9.43	0.48

UN

Observers	FE	Stdev	AE	Stdev
1	11.91	0.71	11.87	0.83
2	10.70	0.83	12.20	1.82
3	8.27	0.91	5.53	1.20
4	8.65	1.59	5.44	0.70
5	11.06	1.19	10.54	0.33
6	9.14	1.24	8.44	0.78
7	10.83	0.58	9.23	0.33
8	10.92	0.55	9.38	1.03
9	9.13	0.43	7.80	0.21

DT

Observers	FE	Stdev	AE	Stdev
1	11.91	0.71	11.87	0.83
2	10.70	0.83	12.20	1.82
3	8.27	0.91	5.53	1.20
4	8.65	1.59	5.44	0.70
5	11.06	1.19	10.54	0.33
6	9.14	1.24	8.44	0.78
7	10.83	0.58	9.23	0.33
8	10.92	0.55	9.38	1.03
9	9.13	0.43	7.80	0.21

UT

Observers	FE	Stdev	AE	Stdev
1	10.02	0.50	10.77	0.86
2	9.44	0.77	10.25	1.18
3	10.44	0.93	9.07	1.39
4	9.94	0.44	8.38	1.46
5	16.57	0.51	13.70	0.64
6	9.62	0.60	11.58	0.87
7	9.62	0.80	11.99	0.35
8	11.02	0.24	11.59	2.18
9	9.43	1.79	13.61	0.18

DN

Observers	FE	Stdev	AE	Stdev
1	6.52	0.54	4.74	0.69
2	9.46	0.29	6.51	0.37
3	6.90	1.01	5.55	0.76
4	7.95	0.82	6.68	0.67
5	10.39	0.74	8.67	1.54
6	6.32	0.43	7.29	0.29
7	5.50	0.78	6.41	0.57
8	7.43	0.64	8.99	1.03
9	9.32	0.81	9.76	0.38

APPENDIX for CHAPTER 9: Effect of amblyopia on the metrics of saccadic eye

DURATION (msecs)

TEM

Observers	FE	Stdev	AE	Stdev
1	61	3	60	10
2	48	3	52	7
3	60	4	60	2
4	53	3	66	10
5	52	7	53	13
6	53	2	47	4
7	65	8	60	9
8	55	4	51	3
9	47	3	63	13

UP

Observers	FE	Stdev	AE	Stdev
1	98	3	82	12
2	56	4	137	28
3	82	10	83	16
4	82	13	94	20
5	75	10	71	22
6	97	4	90	1
7	83	9	73	11
8	114	9	103	7
9	53	3	77	3

UN

Observers	FE	Stdev	AE	Stdev
1	106	3	68	6
2	105	9	107	10
3	99	26	59	7
4	124	26	85	25
5	112	6	52	5
6	54	4	60	9
7	78	15	70	9
8	125	13	106	8
9	81	4	91	2

UT

Observers	FE	Stdev	AE	Stdev
1	64	8	59	3
2	56	6	63	14
3	52	5	77	6
4	66	7	85	14
5	95	10	64	7
6	60	13	47	2
7	68	4	65	9
8	103	6	114	14
9	51	4	90	8

NAS

Observers	FE	Stdev	AE	Stdev
1	64	3	61	1
2	50	2	51	11
3	66	10	57	10
4	53	6	52	3
5	49	7	52	5
6	56	2	60	6
7	78	16	62	5
8	56	6	50	5
9	50	2	52	3

DOWN

Observers	FE	Stdev	AE	Stdev
1	83	11	81	5
2	46	3	52	11
3	62	10	69	19
4	87	11	80	7
5	69	14	68	22
6	70	14	63	12
7	74	11	63	7
8	71	9	59	3
9	65	17	64	4

DT

Observers	FE	Stdev	AE	Stdev
1	71	3	57	3
2	50	3	46	2
3	69	23	67	7
4	62	8	69	5
5	76	16	61	6
6	51	3	50	7
7	68	24	64	8
8	53	2	51	17
9	46	3	62	3

DN

Observers	FE	Stdev	AE	Stdev
1	71	4	58	10
2	45	5	48	10
3	55	3	50	5
4	59	13	71	3
5	63	14	51	7
6	53	2	51	2
7	54	4	65	9
8	49	3	45	1
9	50	3	59	3